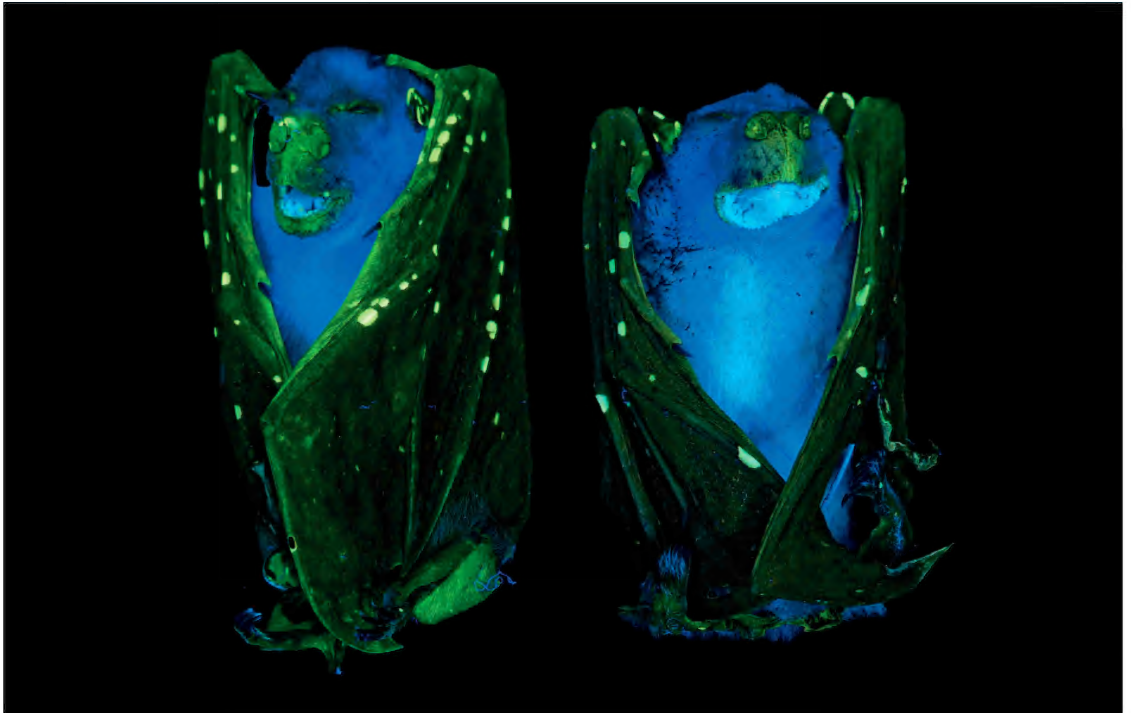


PROCEEDINGS OF
THE ROYAL SOCIETY
OF QUEENSLAND



VOLUME 132

PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND

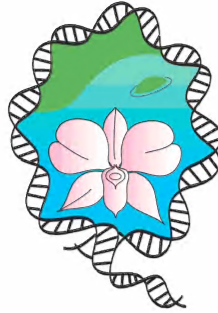
Editors: Julien Louys and Justyna Miskiewicz

Special thanks are extended to the referees who reviewed papers submitted
for publication in this volume of the *Proceedings*.

2023

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COVER ILLUSTRATION

Australian fruit bats fluoresce under ultraviolet light (Credit: Linda Reinhold). While it has been known for some time that certain animals are photoluminescent under ultraviolet light, it was not appreciated how widespread this phenomenon is in mammals until recently. Some impressive new observations have spurred renewed research seeking to document which mammals are fluorescent and under which lighting conditions. Observational data such as these are the critical first steps necessary to building biological hypotheses exploring why mammals should exhibit this characteristic. On pages 3–40, Linda Reinhold explores how widespread fluorescence is in the fur of mammals from the Queensland Wet Tropics, examining 44 species across monotremes, placentals and marsupials.

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Proceedings of The Royal Society of Queensland

The *Proceedings* publishes original scholarship and investigation in natural history relevant to Queensland, including the biodiversity, conservation, use, management and economic significance of natural resources. All aspects of the natural sciences, including astronomy, geology, hydrology, botany and zoology, biomedicine, introduced species and dynamic land and water processes, are considered. The journal will also publish papers on general science, including science-related history, policy, education and philosophy. Papers written from within the social sciences, such as sociology, culture and heritage that deal with the use or management of a natural resource, are welcome.

Following initial appraisal by the Editor, all submitted papers are peer reviewed by a single-blind process. The following types of manuscript are considered:

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EDITORIAL FOREWORD

We are living in a post-truth world. Driven largely by the rise of social media, where opinion is presented as fact and no mechanisms or imperatives exist to ensure the accuracy of statements, our information ecosystem is awash with falsehoods, half-truths, and wolf-whistles to factional groups. The explosion of AI and its growing influence in all facets of the digital age have only exacerbated the problem; for example, Google searches now provide false AI-generated content as leading search results. The fact that Google or social media companies are now the primary source of information for many people brings into question how much more we can move post truth – some would say there's further we can go, as terrifying as this seems.

Science has not been immune to these trends. Sharing manuscripts publicly as pre-prints, whereby manuscripts are posted online prior to peer review, was initially driven by mathematicians and physicists to ensure priority as well as field advancement, given how long it generally takes for mathematical proofs to be ratified. This has since expanded across the natural and social sciences, and the practice is growing in popularity even if many pre-prints do not subsequently end up in the peer-reviewed literature. Alongside pre-prints has been the astronomical growth of predatory publishers, characterised by large stables of journals promising rapid publication, but with minimal to no peer review and high article processing charges (pay-to-publish). Other, more reputable journals are experimenting with the scientific publication process. Journals such as *eLife* no longer have articles accepted or rejected, merely posted pre- and post-peer-review. Such experiments have not been without controversy, as seen in the strong backlash against the claims of burial and rock art by the hominin *Homo naledi* in the South African Rising Star cave system published in the aforementioned journal.

Where does that leave the traditional scientific publication model? Most, if not all academics acknowledge that the current peer-review system is not perfect. It can be subjective, take significant time, and is reliant on the free labour of volunteers who have other, immense professional obligations – few if any rewards are the lot of peer-reviewers. However, such a system serves as a measure of quality, providing reassurance that the claims made in a published scientific paper have been evaluated by experts. Meaningful evaluation cannot and should not be rushed: it ensures that some measure of quality and accuracy can be trusted, and that reputable science is being published. The editorial and copy processes are also, in their smaller way, indispensable. A journal is built on its reputation, which is in turn a form of a brand that can be judged based on its look and content.

It is with these thoughts in mind that we are pleased to present volume 132 of the *Proceedings of The Royal Society of Queensland*. This journal has a sterling reputation which is further supported by the quality of both its past papers and the papers presented herein. In this volume, Reinhold presents data on the fluorescence under ultraviolet light of mammals from the Wet Tropics of Queensland. These important observational data are contributing to a much wider appreciation of this phenomenon in mammals, data critical to developing hypotheses exploring why this might be the case. A pair of fruit bats fluorescing grace this year's cover. Rix explores the work of Benjamin Dunstan and delves into the history of why certain geological treasures left Queensland. Nielsen and Kumarasuriyar explore another facet of Queensland's scientific history with a description of the contributions of Walter Hill, Director of Brisbane's Botanic Gardens. These history of science papers are critical, for how can we understand where we are going unless we know where we have come from? Rounding out this volume is a book review and the annual presidential address. We appreciated the opportunity to edit *Proceedings* for the last three years, and although we are stepping down, we look forward to seeing what new Queensland wonders future volumes will bring, knowing we can trust in the science emerging from this august society and its *Proceedings*.

Julien Louys & Justyna Miszkiewicz
Editors, PRSQ Volume 132, 2023

The Royal Society of Queensland acknowledges the Iningai Nation, their long custodianship and inherent connection to country, its springs and waterways, plants and animals.

We pay respect to the knowledge and cultural values of First Peoples of Australia and acknowledge Elders past, present and future.

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Refereed Papers

Widespread Fluorescence in the Fur of Mammals of the Australian Wet Tropics

Linda Melissa Reinhold¹

Abstract

The sporadic reporting of fluorescent mammal discoveries has led to the trait being considered atypical. However, this perception may be misleading considering that most mammal species have not been examined. Therefore, I made a targeted attempt to assess the scope of fur fluorescence within one bioregion, the Wet Tropics of Far North Queensland, Australia. A series of 148 fresh, old and frozen wild mammals, mostly roadkill, were examined for the presence of fluorescence in their fur. Two species of monotreme, 20 of marsupial and 22 of placental were collected. Torches of various excitation wavelengths revealed that 95% of all mammal species I was able to examine from the Australian Wet Tropics had at least a low level of fluorescence visible in the fur. Fifty per cent of the mammal species had noticeably mid-to-bright fluorescent fur: 16% had strong pink fluorescence; 43% had strong blueish or other coloured fluorescence; and 9% had both. These observations recalibrate our understanding of mammalian fluorescence to be a somewhat ubiquitous feature of fur chemistry.

Keywords: marsupial, monotreme, placental

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Introduction

Photoluminescence (fluorescence and/or phosphorescence) is an inherent property of most biological tissues (Stübel, 1911; Niyangoda et al., 2017; Chen et al., 2018), whereby if the excitation light is ultraviolet and the re-emission is in the visible spectrum, the organism can appear to glow (Baird, 2015). Although best known from marine environments (Sparks et al., 2014), fluorescence and/or phosphorescence is also a trait of many terrestrial invertebrates (Lawrence, 1954), amphibians (Hadjioloff & Zvetkova, 1978), reptiles (Prötzel et al., 2021), birds (Pohland, 2007) and mammals (Pine et al., 1985).

Photoluminescence, phosphorescence and fluorescence all define the absorption and re-emission

of light, changing its colour to a longer wavelength (Valeur & Berberan-Santos, 2011). The word ‘phosphorescence’ was already in use for the same phenomenon Stokes (1852) coined as ‘fluorescence’. Stokes’s ‘fluorescent’ biological substances were actually phosphorescent (Wilson & Beccari, 1776; Giese & Leighton, 1937). Becquerel (1867) demonstrated how the refrangibility of light that Stokes (1852) had described was the same as the existing phosphorescence, with some lasting a longer or shorter duration than others. Becquerel (1867) therefore recommended that the term ‘fluorescence’ be abandoned. Whilst both terms described the effect of objects glowing under short-wavelength excitation, it was not until much later (Perrins, 1929, cited in Valeur & Berberan-Santos,

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2011) that Stokes's (1852) new word was given a definition that separated it from phosphorescence. The terms were then separated on an atomic basis, with the electrons involved in fluorescence in a singlet state, and the electrons involved in phosphorescence temporarily residing in an intermediate triplet state (Perrins, 1929, cited in Valeur & Berberan-Santos, 2011). Hence, fluorescence generally ceases when the excitation light stops, and phosphorescence usually, but not always, has a longer afterglow. The word 'photoluminescence' is inclusive of both states. There is no atomic reason why fluorescence should have overtaken phosphorescence as the default word for photoluminescence; rather, it reflects a shift in popular language.

During the 1700s, phosphorescence (photoluminescence with an afterglow) was described in fur, wool and hair (Wilson & Beccari, 1776). Both fluorescence and phosphorescence of tryptophan metabolites have been described extensively in the most-studied example of mammalian photoluminescence (sheep's (*Ovis aries*) wool: Leaver, 1978; Smith & Melhuish, 1985; Collins, 1992). The aromatic amino acids tryptophan, tyrosine and phenylalanine in keratin are the only ones known to cause both fluorescence and phosphorescence of proteins in a free state (Konev, 1967; Pailthorpe & Nicholls, 1972). Porphyrins are also capable of both fluorescing and phosphorescing (Gouterman & Khalil, 1974; Feitelson & Mauzerall, 1982). However, most studies on the pelage of mammals have not gone to the detail of atomically differentiating phosphorescence from fluorescence. The popular term 'fluorescence' is used throughout this article in line with recent usage.

Attempts have been made at shoehorning life-style patterns of fluorescent mammals into selected datasets. For example, from a dataset of only three publications, Gray & Karlsson (2022) calculated that 100% of mammals with fluorescent fur were nocturnal, but only by excluding the majority of published cases of fur fluorescence from the analysis, such as diurnal species (e.g. gerbils (Gerbillinae), Udall et al., 1964). The dominant mammal fluorescent colours were narrowed down to pink and purple, again by excluding most of those species that fluoresced in different colours (e.g. rats (*Rattus* spp.), Udall et al., 1964). Despite a wealth of literature,

the widespread nature of fluorescence in fur, particularly in familiar domestic and diurnal species, has been overlooked (Reinhold, 2023).

Fluorescent fur occurs in mammals from a range of forest and desert environments, from snow-covered landscapes to the tropics worldwide (Kohler et al., 2019; Olson et al., 2021; Toussaint et al., 2023). Fluorescence in the fur of an Australian mammal, the common brushtail possum (*Trichosurus vulpecula*), has been described in detail (Bolliger, 1944; Nicholls & Rienits, 1971), but this is seldom cited. Other Australian mammals are also known to fluoresce, with Bolliger (1944) describing the trait as "not uncommon". Pine et al. (1985) examined museum specimens of Australian mammals for fluorescence but found it to be mild in comparison to American didelphid marsupials. Fluorescence in Australian mammals was then largely forgotten until recently (Reinhold, 2020, 2021; Anich et al., 2021).

With instances of fur fluorescence being reported sporadically worldwide, it is difficult to ascertain the rarity of the trait across mammal taxa. Fur fluorescence has been recently assumed as rare in non-didelphid mammals (Anich et al., 2021; Olson et al., 2021). However, over the last 112 years, fluorescence has been recorded in the fur of half of all mammal orders (Reinhold, 2023). Locally, Reinhold (2021) reported fur fluorescence in all five mammal species observed live in the Wet Tropics of Queensland. Gershwin (2022) described fluorescence in the fur of all six fresh roadkill Tasmanian marsupial species examined (three of which fluoresced pink). However, in the two species of bandicoot (southern brown bandicoot (*Isodon obesulus*) and eastern barred bandicoot (*Perameles gunnii*)) that were examined both as fresh roadkill and taxidermied museum specimens, only the fresh roadkill displayed fluorescence of the fur. Three of 15 species that were examined only as taxidermied museum display specimens had fluorescent pelage, but 14 of the taxidermied species showed fluorescence of skin parts. Toussaint et al. (2023) reported fluorescent fur from 12 of 18 species examined in European museums (of which the four didelphid marsupial species (brown-eared woolly opossum (*Caluromys lanatus*), Linnaeus's mouse opossum (*Marmosa murina*), brown four-eyed opossum (*Metachirus*

nudicaudatus) and Guyanan short-tailed opossum (*Monodelphis brevicaudata*), the four flying squirrel species (southern flying squirrel (*Glaucomys volans*), northern flying squirrel (*Glaucomys sabrinus*), red-cheeked flying squirrel (*Hylopetes spadiceus*) and smoky flying squirrel (*Pteromyscus pulverulentus*)) and both hedgehog species (West European hedgehog (*Erinaceus europaeus*) and northern white-breasted hedgehog (*Erinaceus roumanicus*)) fluoresced pink, whereas only two other species (platypus (*Ornithorhynchus anatinus*) and Beringian ermine (*Mustela erminea*)) fluoresced in other colours). Tumilson & Tumilson (2021) found strong fluorescent properties in the fur of seven (and mild fluorescence in a further two) species of 37 Arkansas (USA) museum mammal species examined (of which only the one species of didelphid (Virginia opossum (*Didelphis virginiana*)) fluoresced mid-to-bright pink, but some eastern chipmunks (*Tamias striatus*) turned mild pink on their ventral fur). However, a reliance on museum specimens can be problematic, with some fluorophores destroyed by exposure to light (porphyrins, Hill, 2010) or by wet preservation (Reinhold, 2023). Artificial fluorescent stains are also sometimes inadvertently added to dry skins during taxidermy (Pohland, 2007). Particular care should be taken with older specimens that have undergone export-import procedures and therefore are likely to have been treated with a green-fluorescent fumigant such as carbon disulphide or methyl bromide (Bond & Monro, 1984; Gackowska et al., 2003; Rajendran & Parveen, 2005), the effects of which are untested but likely to overwhelm more subtle true-to-life fluorescent colouration.

Fresh and frozen materials are needed to verify true-to-life labile fluorescent colours. The abundance of roadkill animals in the Wet Tropics of Far North Queensland, Australia, provided an opportunity to document the occurrence of fluorescence in the fur of unpreserved mammals from one bioregion. This investigation aimed to assess how widespread and varied the phenomenon of fluorescent fur is across mammal taxa in the Wet Tropics region of Australia. I predicted that, if fluorescence varied between species, the trait would separate on some taxonomic or external factor such as marsupial/placental, habitat (lowland/tableland), diet, nocturnality, or tree-dwelling

versus ground-dwelling. The study presented here represents the most thorough documented examination of fluorescence in fresh and frozen mammal material to date.

Methods

A total of 63 mammals was sourced, mostly as roadkill, from within a two-hour drive of the city of Cairns in Far North Queensland, Australia. Twelve dedicated night and pre-dawn collecting trips, totalling 1330 km over 36 hours, were conducted between August 2021 and June 2023. Pre-dawn was often chosen because this gave the greatest length of time for roadkills to occur, and allowed access to them before the sun caused photobleaching. Roadkill animals were also sampled opportunistically on the Atherton Tablelands at night and at dawn, and during the day while driving around the Wet Tropics region over this same period. Four of the animals were found dead from other causes in suburbia. After the collection of each animal, I recorded date, time, weather, GPS coordinates, habitat, species, sex and orientation of the carcass (dorsal, ventral, lateral facing up) if the animal had been exposed to sunlight. Animals were identified to species using field guides (Covacevich & Easton, 1974; Churchill, 2008; Menkhorst & Knight, 2011). Animals found at night were often moved off the road and examined on site. If animals were found nearing or in daylight hours, carcasses were collected whole, wrapped in labelled aluminium foil and plastic bags, and loaded into an insulated cold box (onto a Styrofoam layer over freezer gel packs). Specimens were transported back to my home for processing in a dark garage later that night/day. For larger animals such as macropods found in daylight, fur samples were shaved from the dorsal, flank and ventral sides, tail and/or rump, and stored in aluminium foil inside plastic bags for later examination in a dark laboratory.

A total of 85 mammals was also examined from local freezer stores at the Atherton Queensland Parks and Wildlife Service office (QPWS; $n = 15$), the James Cook University (JCU) Smithfield campus ($n = 52$), the Tolga Bat Hospital ($n = 17$) and Kings Plains Station ($n = 1$). Rangers, researchers, landholders and other members of the public bring carcasses (from car strikes, dog attacks, barbed wire fences or unknown causes) into these institutions to donate to

scientific research. Most of the animals from the JCU freezers did not have location data but were assumed to be from the Wet Tropics region. Animals with data dated back to 1995. For freezer-stored animals that had been collected by others, there were no data as to how much sunlight they had been exposed to or which way up they had been facing when found. Therefore, the amount of post-mortem fluorophore degradation was unknown. Specimens that had intact skulls and date and location data were sent to the Queensland Museum. From my collecting and JCU, the northern bettongs (*Bettongia tropica*) and some of the small species were sent as whole frozen carcasses, but other species were sent only as heads for the extraction of skulls as per museum requirements. The specimens from QPWS and Kings Plains Station were sent to the museum by those institutions as whole frozen carcasses. The source of each specimen is listed in Appendix 1.

From all collection methods combined, 148 mammals, comprised of 44 species, were examined for external fluorescence. This sample represents 31% of the terrestrial mammal species found in the Wet Tropics region (Department of Environment and Science, 2013). The specimens included 28% of the wild placental species (33% of rodent species, 26% of bat species and 20% of introduced/naturalised species), 33% of marsupial species and both monotreme species. Frozen specimens were thawed before examination, except for those kept for other research. The pelage of each animal was examined for fluorescence at several wavelengths using a range of ultraviolet, violet and blue torches at 310 (range 295–330 nm, Tao Yuan, 10–15 mW, 160 mA, 1 × LED UVB, 1 × 18650 lithium-ion cell), 365 (LED shop, 3 W, LED, 3 × AAA cell; Olight i5UV Camo, 1500 lumens, LED, 1 × AA cell; UV Beast V3 UVB-V3-365, 5400 $\mu\text{W}/\text{cm}^2$ UV irradiance, 1350 nW UV radiant intensity, 3.7 V, 3 × LED, 2 × 18650 lithium-ion cells), 380 (range 350–420 nm, Proconctech ST3386UV, 4 × LED, 3 × AAA cells), 395 (Capsulone LD1345, LED, 3 × AAA cells), 395–410 (Dulex DX-502B, 3.7 V, LED, 1 × 18650 lithium-ion cell) and 470 nm (UltraFire H-b3, 283 lumens, 3.7 V, 3 × XP-E2 LED, 1 × 18650 lithium-ion cell).

Because quantitative measurement was not feasible when using different torches (and different battery strengths) to elicit fluorescence,

I qualitatively described the reaction of the fur to light of various wavelengths. The categories were: 'none' if there was no perceptible fluorescence; 'low' if it was difficult to tell whether the fluorescence was greater than that expected by ubiquitous background levels, or if I had to look closely to see it, it appeared as a faint colour change without a glow, or if it was clearly visible but only mild; 'mid' if the fluorescence was obviously visible as a colour change and/or a glow, but not strikingly bright (the fluorescence of human fingernails falls into this category); and 'bright' if the fluorescence was striking, vivid, with a colour change and/or glow that stood out as remarkable against the background. These categories were divided on a continuum. In some species, the fluorescence was over all the fur; yet in others, there were areas of brighter fluorescence beside areas that had low fluorescence. Species with smaller areas of fluorescence were categorised on the overall effect on the whole animal. Categorisation of mid versus bright fluorescence in some species, and/or its restricted nature across the pelt, sometimes made separation subjective. Therefore, only three categories were used in the calculations of percentages: none, low and mid-to-bright.

I recorded observations of fluorescence directly from the carcasses, not from photographs. Due to the variable nature of the torch distance and battery power, photographs act only as a qualitative record to visually document these observations, and not a way to quantitatively compare fluorescence between animals. All photographs were taken with a Panasonic Lumix TZ-80 camera and not enhanced by filtering or post-processing. Photography was conducted on whole animals, with the background varying from dirt/gravel or grass by roadsides, the plastic bags in which they had been frozen for messier specimens in the laboratory, or black cloth where feasible. Whether the sides of the animals photographed were dorsal and ventral or left and right lateral depended on the position the animal had stiffened into during rigor mortis. A CrimeTech 8 cm L-shaped greyscale ruler was placed in the corner of each photograph for scale. The ruler also acted as a standard for light reflection. Unless specified, the appearance of purple in the photographs is from reflected violet torchlight. Depending on distance and brightness,

the camera lens was open for 5–30 seconds as each torch scanned the animal. Torch beams were shone over the animal just out of sight of the camera lens, or farther away for the brighter torches. Other camera settings were automatic.

Results

Fluorescence was a common trait among Wet Tropics mammals, with 95% of species examined showing at least a low-level glow or colour change in their fur. Fifty per cent of all mammal species displayed mid-to-bright pink and/or blue/other coloured fluorescence in their fur (65% of marsupials and 41% of placentals). Blue, white, greenish or other

non-pink fluorescence was approximately twice as common as pink fluorescence. Table 1 summarises the relative brightness of pink-orange (excited at wavelengths ~395 nm) and other coloured (excited at wavelengths 310–410 nm) fur fluorescence for each species, scored as none, low, mid or bright. Table 1 also assigns each species examined a simplified lifestyle category of diet, stratification and nocturnality. However, many species had a more complex combination within each parameter that was not taken into account (e.g. a species may be variably folivorous, frugivorous and fungivorous). Crepuscular and nocturnal-crepuscular species were all categorised as nocturnal.

Table 1. Fur fluorescence and lifestyle characteristics of Wet Tropics wild mammal species examined.

Species	Pink	Other colour	Diet	Stratification	Nocturnality
Monotremes					
<i>Ornithorhynchus anatinus</i>	low	low	carnivorous	amphibious	either
<i>Tachyglossus aculeatus</i>	none	low	insectivorous	ground	either
Marsupials					
<i>Antechinus adustus</i>	low	bright	insectivorous	semi-arboreal	diurnal
<i>Dasyurus hallucatus</i>	bright	mid	carnivorous	semi-arboreal	nocturnal
<i>Sminthopsis</i> sp.	low	low	carnivorous	ground	nocturnal
<i>Isoodon macrourus</i>	bright	low	omnivorous	ground	nocturnal
<i>Perameles pallescens</i>	bright	mid	omnivorous	ground	nocturnal
<i>Acrobates pygmaeus</i>	low	none	nectivorous	arboreal	nocturnal
<i>Dendrolagus lumholtzi</i>	none	bright	folivorous	arboreal	nocturnal
<i>Notamacropus agilis</i>	none	low	folivorous	ground	nocturnal
<i>Thylogale stigmatica</i>	low	mid	folivorous	ground	diurnal
<i>Wallabia bicolor</i>	none	low	folivorous	ground	diurnal
<i>Dactylopsila trivirgata</i>	none	bright	insectivorous	arboreal	nocturnal
<i>Petaurus notatus</i>	low	mid	insectivorous	arboreal	nocturnal
<i>Trichosurus johnstonii</i>	mid	mid	folivorous	arboreal	nocturnal
<i>Trichosurus vulpecula</i>	mid	bright	folivorous	arboreal	nocturnal
<i>Aepyprymnus rufescens</i>	mid	low	fungivorous	ground	nocturnal
<i>Bettongia tropica</i>	mid	low	fungivorous	ground	nocturnal
<i>Petauroides minor</i>	none	low	folivorous	arboreal	nocturnal
<i>Pseudochirops archeri</i>	low	low	folivorous	arboreal	nocturnal
<i>Pseudocheirus peregrinus</i>	none	low	folivorous	arboreal	nocturnal
<i>Pseudochirulus herbertensis</i>	low	mid	folivorous	arboreal	nocturnal

Species	Pink	Other colour	Diet	Stratification	Nocturnality
Placentals					
<i>Oryctolagus cuniculus</i>	low	mid	herbivorous	ground	nocturnal
<i>Mesembriomys gouldii</i>	low	none	frugivorous	arboreal	nocturnal
<i>Pogonomys mollipilosus</i>	low	low	frugivorous	arboreal	nocturnal
<i>Pseudomys delicatulus</i>	none	bright	granivorous	ground	nocturnal
<i>Rattus fuscipes</i>	none	bright	herbivorous	ground	nocturnal
<i>Rattus rattus</i>	none	bright	omnivorous	semi-arboreal	nocturnal
<i>Rattus tunneyi</i>	none	bright	herbivorous	ground	nocturnal
<i>Uromys caudimaculatus</i>	low	low	omnivorous	semi-arboreal	nocturnal
<i>Nyctimene robinsoni</i>	none	bright	frugivorous	volant	nocturnal
<i>Pteropus conspicillatus</i>	none	mid	frugivorous	volant	nocturnal
<i>Pteropus scapulatus</i>	none	low	nectivorous	volant	nocturnal
<i>Chalinolobus gouldii</i>	none	none	insectivorous	volant	nocturnal
<i>Chalinolobus nigrogriseus</i>	none	none	insectivorous	volant	nocturnal
<i>Hipposideros diamema</i>	none	low	insectivorous	volant	nocturnal
<i>Macroderma gigas</i>	low	mid	carnivorous	volant	nocturnal
<i>Miniopterus orianae</i>	none	low	insectivorous	volant	nocturnal
<i>Ozimops lumsdenae</i>	low	low	insectivorous	volant	nocturnal
<i>Ozimops ridei</i>	none	low	insectivorous	volant	nocturnal
<i>Nyctophilus bifax</i>	none	low	insectivorous	volant	nocturnal
<i>Rhinolophus megaphyllus</i>	none	mid	insectivorous	volant	nocturnal
<i>Vespudelus</i> sp.	none	low	insectivorous	volant	nocturnal
<i>Canis familiaris</i>	none	low	carnivorous	ground	nocturnal

The various wavelengths of the torches used elicited different colours of fluorescence. The 470 nm blue-light torch generally did not elicit fluorescence and was too bright for close-range examination. When animals emitted fluorescence in shades of pink or orange, it was invariably brightest at the longer excitation wavelengths around 395 nm (this spectrographic signature correlates to porphyrin-derivative fluorophores: Goldoni, 2002; Olson et al., 2021; Toussaint et al., 2023). Blue-coloured fluorescence was usually brightest when excited at 365 nm (from other causes or correlating to other fluorophores, including tryptophan metabolites: Rebell et al., 1957; Nicholls & Rienits, 1971). Greenish fluorescence was optimally excited at the longer wavelengths. Therefore, fluorescence has been separated on emission colour, categorised as

either pink (optimally excited at 395–410 nm, presumed porphyrin based) or blue/other (optimally excited at 310–410 nm). Species could display either the pink or the blueish type of fluorescence, or both when examined at different excitation wavelengths or with the 380 nm torch. Unless mentioned specifically, the skin did not glow brightly. Claws and eyes often fluoresced pale blue.

Pink or orangish fluorescence (optimally excited by longer wavelengths of 395–410 nm) was present in the fur of 48% of the species examined but was at a reasonably strong level in only 16% of species. No placental mammals had mid-to-bright pink fluorescence, but 27% had a low level, with the remaining 73% displaying no pink fluorescence (Figure 1). One of the monotreme species had low pink fluorescence, and the other had none.

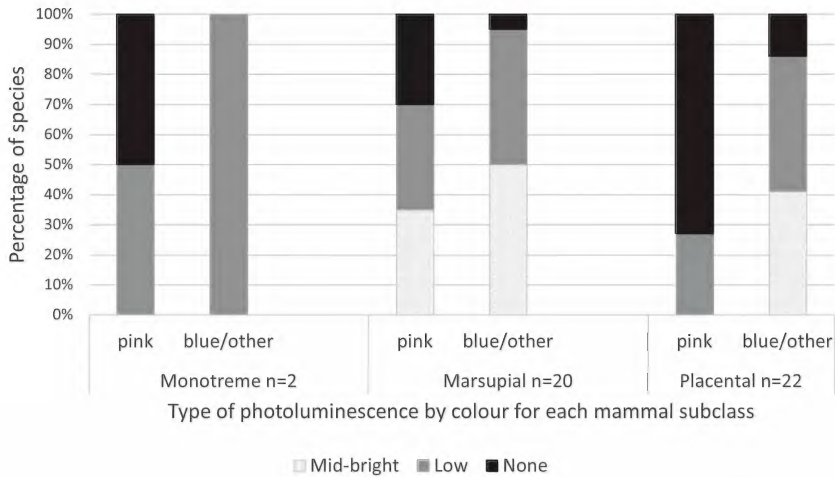


FIGURE 1. Relative brightness of fluorescence in Wet Tropics mammal species. Categorised as pink/orangish (optimal excitation 395–410 nm) or blueish/other colours (optimal excitation 310–410 nm).

Of the marsupial species, 35% had prominent mid-to-bright pink fluorescence. A further 35% of marsupial species had low pink fluorescence, and the remaining 30% had none. Mid-to-bright pink fluorescence was restricted to nocturnal species, but low-level pink fluorescence was found in 60% of species with diurnal tendencies. Mid-to-bright pink fluorescence occurred in 20% of primarily folivorous species, 25% of carnivorous species, 50% of omnivorous species and 100% of fungivorous species. No insectivores, frugivores or granivores fluoresced bright pink. Mid-to-bright pink fluorescence was distributed across 21% of ground-dwelling species, 25% of semi-arboreal species and 17% of arboreal species, but not amphibious or volant (Table 1). Pink or reddish colourations were never seen in the teeth, exposed bones, or skin of the animals.

Blue or other-coloured fluorescence (excited by wavelengths of 310–410 nm) was present in the fur of 91% of all species examined and was at a reasonably strong level in 43% of all species. Forty-one per cent of placentals had mid-to-bright non-pink fluorescence, in 45% fluorescence was low, and in 14% there was none that was perceptible (Figure 1). Both monotreme species had low non-pink fluorescence. Of the marsupial species, 50% had mid-to-bright non-pink fluorescence. A further 45% of marsupial species had low

non-pink fluorescence, and 5% had none. Mid-to-bright blueish or other coloured fluorescence occurred in 67% of primarily diurnal marsupial species and in 47% of nocturnal or nocturnal/crepuscular marsupial species. All placental species examined here were nocturnal, and the monotremes were either diurnal or nocturnal. Mid-to-bright blue or other coloured fluorescence occurred in 50% of primarily folivorous species, 40% of carnivorous species, 50% of omnivorous species, 31% of insectivorous species, 50% of frugivorous species, 100% of herbivore generalist species and the only granivorous species. Bright blueish fluorescence was absent only from fungivorous and primarily nectivorous species. Mid-to-bright blue or other coloured fluorescence was distributed across 43% of ground-dwelling species, 75% of semi-arboreal species, 50% of arboreal species and 31% of volant species, but not amphibious (Table 1).

Variation over the species examined precluded further analyses on determining predictive factors for fluorescent fur. Taxon-specific descriptions of fur fluorescence are provided below, grouped by order and family, and generalised for the most intact specimens of each species. Descriptions of fur fluorescence in each of the 148 individual specimens, for both 310–365 and 380–410 nm excitation wavelength ranges, are listed in Appendix 1.

Monotremes (2 species; $n = 4$)

Order Monotremata

Platypus and Echidna. Families Ornithorhynchidae and Tachyglossidae. Both monotreme species showed only subtle fluorescence in some of their fur, best viewed close and dominated by a faint moss green. The green was evident only at the longer 380–410 nm wavelengths, not at 310–365 nm. Platypuses (*Ornithorhynchus anatinus*; $n = 2$) also had a silvery grey fluorescence visible at the shorter wavelengths, and pale pink at the longer wavelengths, though the pink was evident only on close inspection of clipped fur. The spines of the short-beaked echidnas (*Tachyglossus aculeatus*; $n = 2$) fluoresced greenish yellow, but no more than expected from keratin. The intact short-beaked echidna had an area of fluorescent blue skin, particularly near the cloaca. The part of the echidna that showed the most fluorescent green was the highly keratinised fur on the tops of the front paws.

Marsupials (20 species; $n = 104$)

All marsupial species displayed some level of fluorescence in their fur when exposed to ultraviolet or violet excitation wavelengths. The striped possums, antechinuses and tree-kangaroos gave a brilliant blue-white fluorescence. Only the quolls and the bandicoots displayed stunningly bright pink fur. The brushtail possums and the bettongs also fluoresced a remarkable pink, but in a softer hue (Figure 2).

Order Dasyuromorphia

Quolls, Antechinuses and Dunnarts. Family Dasyuridae (3 species). Dasyurids mostly displayed bright fluorescence. Antechinuses (*Antechinus* sp.; $n = 2$, treated as the same species) had bright blue-white fluorescence all over. The blue-white was brightest at 365 nm (Figure 2A). One specimen had a slight pink wash around the rump at 395–410 nm. The oldest specimen, dating to 1995, still fluoresced blue-white, the same colour as another frozen specimen only a few months old, and live animals (Reinhold, 2020), but the intensity and extent of the fluorescence was a little dull compared to fresher animals. A dunnart (*Sminthopsis* sp.; $n = 1$) also displayed pale pink (also whitish) fluorescence at longer wavelengths.

The northern quolls (*Dasyurus hallucatus*; $n = 9$) had bright pink fluorescence, similar in intensity to that of bandicoots. Nearly half of the quoll specimens, both male and female, displayed intense, strong, dark pink fluorescence throughout their fur, both in the brown flanks and through the white spots (Figure 2E). Most specimens had paler pink on their ventral surface. A specimen gathered as a roadkill that had been in the sun for several hours retained the pink fluorescence on the side that was facing down protected from the sun but had lost all trace of pink from its exposed surface. The pink fluorescence was elicited only at the longer wavelengths. Some of the male quolls also had a yellowish green fluorescence on the sides of their necks/shoulders. The chest patch fluoresced bright lemon yellow, particularly in the fresh roadkill.

Order Peramelemorphia

Bandicoots. Family Peramelidae (2 species). Both northern brown (*Isodon macrourus*; $n = 22 + 4$ pouch young) and northern long-nosed bandicoots (*Perameles pallescens*; $n = 14 + 2$ pouch young) displayed bright pink fluorescence all over their fur. Both species of bandicoot showed intraspecies variation in the coverage and intensity of fluorescence, but always displayed pink (all but one bandicoot were collected as fresh roadkill). Brightly vivid pink was observed to be most intense and entire in virginal (independent but with undeveloped pouch or testes) individuals of both sexes, although the vividness of pink varied within this size class. Some adult male bandicoots displayed uniform bright pink fluorescence, but in others of the same size it was patchy. Other animals, not collected, that were rotting and seemed to have been lying by the road for several days, retained their pink fluorescence in the fur underneath the animal. Adult male roadkill northern long-nosed bandicoots displayed two fluorescent colour morphs, with white and blue fluorescence more prominent on the pale-flanked and/or banded individuals. In these individuals, the pink wash on the ventral surface was caused by longer pink strands visible above a uniform bright white fluorescence given by the short, fine ventral fur strands. Blue was also seen around the necks of some female northern long-nosed bandicoots (Figure 2D). The blue and white fluorescence was observed only in one female northern brown bandicoot with

pouch young. I could not determine any difference in fluorescence between lowland and tableland individuals, as only three northern brown bandicoots were collected from the tablelands, and only one northern long-nosed bandicoot was collected from the lowlands.

Order Diprotodontia

Feathertail Gliders. Family Acrobatidae (1 species).

A feathertail glider (*Acrobates pygmaeus*; $n = 1$) showed no blueish white fluorescence at shorter wavelengths, but her face and venter turned slightly apricot pink at longer wavelengths.

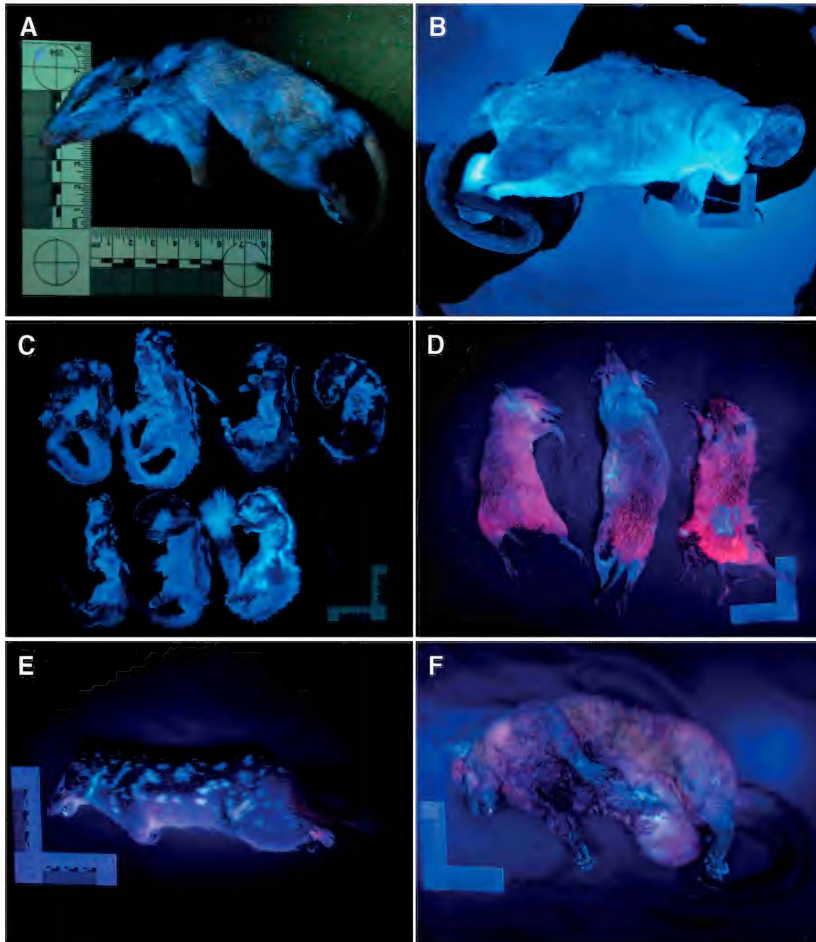


FIGURE 2. Fluorescence of Wet Tropics marsupial mammals. (A) *Antechinus*, male, frozen. Displaying bright light-blue fluorescence all over in 365 nm torchlight (15 s exposure). (B) Lumholtz's tree-kangaroo, male, frozen-thawed. Bright light-blue fluorescence all over in 365 nm (10 s). (C) Striped possums, 8 × male, frozen-thawed. Bright blueish white fluorescence of white fur in 365 nm (30 s; eighth carcass severely degraded). (D) Northern long-nosed bandicoots, female-male-female, fresh roadkills. Bright pink fluorescence all over; necks also light blue, particularly on the male. In 395–410 nm (20 s). (E) Northern quoll, male, frozen. Pink fluorescence over flank, ventral, feet and tail, but most suspected to have been lost from this specimen. Some greenish fluorescence to the neck/shoulder. In 395–410 nm (10 s). (F) Coppery brushtail possum, female, fresh roadkill, fluorescing soft pink in 395–410 nm (10 s).

Wallabies, Tree-kangaroos and Pademelons.

Family Macropodidae (4 species). Frozen-thawed Lumholtz's tree-kangaroos (*Dendrolagus lumholtzi*; $n = 2$) fluoresced bright pale blue consistently throughout their fur, much stronger at 365 nm than at 395 nm (Figure 2B). Fresh roadkill red-legged pademelons (*Thylogale stigmatica*; $n = 3$) had quite a bright blue-white glow, most evident at 365 nm, especially on their paler ventral fur. At 380–410 nm, they had a subtle dusky pink fluorescence mostly in their flank and ventral fur. The grey-coloured dorsal fur turned a light purple most strongly in 365 nm torchlight. The purple was brighter than reflectance and probably represented fluorescence. Roadkill swamp wallabies (*Wallabia bicolor*; $n = 2$) were minimally fluorescent, with only a faint white glow or a slight yellowish colour. A fresh roadkill agile wallaby (*Notamacropus agilis*; $n = 1$) had a mild white glow to the pale ventral fur, most evident at 365 nm.

Gliders and Striped Possums. Family Petauridae (2 species). Krefft's gliders (*Petaurus notatus*; $n = 4$) gave a pale blueish white glow all over, unusually most prominent when excited at 310 nm. At longer wavelengths, a mild dusky pink colouring became visible over the entire ventral fur of three out of four individuals. The colour was quite faint in comparison with the pink fluorescence of other species.

Striped possums (*Dactylopsila trivirgata*; $n = 9$) were striking, with a brilliant white, almost greenish blue-white glow bordered by non-fluorescent black stripes (Figure 2C). The glow was more distinct at the shorter wavelengths. The fresher-looking of the frozen-thawed individuals had the brightest glow. However, a badly decomposing animal (not pictured) had retained blue-white fluorescence on its upper surface after several days by the side of the road.

Brush-tail Possums. Family: Phalangeridae (treated as 2 species). The brush-tail possums had both blueish and pink fluorescence. On the common brush-tails (*Trichosurus vulpecula*; $n = 3$), there was a strong sky-blue fluorescence both dorsally and ventrally, brightest at the shorter wavelengths. The pink fluorescence responded optimally to the longer wavelengths. Pink fluorescence also occurred both dorsally and ventrally, variably in

either the proximal or the distal parts of the fur shaft. The coppery brushtail possums (*Trichosurus johnstonii*; $n = 3$) displayed fluorescence generally similar to that of the common brushtail possums. Some of the chest gland fur of the male fluoresced pale yellow. The male's pink fluorescence occurred patchily, but along whole strands of fur. A very fresh roadkill had pale purply blue-grey fluorescence on her face, arms, skin and basal half of underfur. This purply fluorescence was more prominent in 310 nm than in 365 nm torchlight, disappearing at 380 nm and above. At 395–410 nm, the same basal underfur instead fluoresced orangey pink (Figure 2F). This indicates two fluorophores activated separately in the same fur. The same animal had a particularly strong orange-pink patch of fluorescent fur on her rump, presumably newly regrown (Bolliger, 1944).

Bettongs. Family Potoroidae (2 species). The bettongs fluoresced pink, but at a much lesser intensity than the bandicoots and quolls. The northern bettongs (*Bettongia tropica*; $n = 9$) had pink fluorescence throughout the dorsal and flank fur, with not so much on the ventral fur. A mild greenish yellow fluorescence occurred along the ventral tail fur in some individuals, and the ear fur of one fluoresced mild green-blue-white. The flanks of the rufous bettong (*Aepyprymnus rufescens*; $n = 3 + 1$ pouch young) roadkill specimens had reasonably strong pink fluorescence. The pink was in whole thicker whitish strands and throughout the softer fur. The dorsal surface of the animals had darker pink fluorescence at the bases of the fur, and white tips. The ventral surface also fluoresced pink, but a lighter shade. Over the dorsal surface and particularly on the hindquarters, a blueish white fluorescence was flecked through the fur at 365 nm, and much less so at 380–410 nm. Here, the underfur also glowed light purplish white, a different shade than that reflected, and only initiated by shorter wavelengths that did not have as much visible purple in their beam.

Ringtail Possums and Greater Gliders. Family Pseudocheiridae (4 species). All the ringtail possums fluoresced somewhat, but none brightly so. A common ringtail possum (*Pseudocheirus peregrinus*; $n = 1$) had greenish white fluorescence flecked through the dorsal and flank fur, particularly on his cheek. His tail and ventral fur fluoresced white.

In Herbert River ringtail possums (*Pseudochirulus herbertensis*; $n = 3$), the white fur of the male glowed white. One female had a pale greenish fluorescence in the fur tips. The other female had a pink wash in some of her fur.

The green ringtail possums (*Pseudochirops archeri*; $n = 10$) did not have as striking a fluorescence as anticipated from their white-light markings. However, the markings did stand out more in ultraviolet light than they did in white light. The yellow fur tips appeared a brighter pale greenish yellow in ultraviolet torchlight. Some dusky pink fluorescence was noted through the dorsal underfur, tail and edging the ventral areas. Fluorescence was only really evident on the roadkills and the QPWS freezer specimen, not on the JCU freezer specimens. The northern greater gliders (*Petauroides minor*; $n = 2$) fluoresced only pale grey and a little white ventrally, and did not exhibit any pink.

Placentals (22 species; $n = 38$)

The *Rattus* species and the delicate mouse (*Pseudomys delicatulus*) had brilliant blue-white fluorescence in similar colour and intensity to the antechinuses and tree-kangaroos of the marsupials. Three species of bat had mid-to-bright fluorescence, either blue or green-yellow (Figure 3). The fur fluorescence of the other placental species tended to be very mild. Six placental mammal species, including the native non-*Rattus* rat species, the introduced European rabbit and two microbats, had traces of pink or orange fluorescence in their fur, but none so brightly as the marsupials.

Order Lagomorpha

Rabbits. Family Leporidae (1 species). European rabbits (*Oryctolagus cuniculus*; $n = 3$), of wild brown and grey coat colouration, had minimal fluorescence. At 365 nm, the ventral fur fluoresced mild whitish, but bright white on the underside of the tail and below the tail (Figure 3A). At 395–410 nm, some pale pink was visible in the pale buff tips and strands of ventral fur. Some whole strands fluoresced pale pink in some small patches of otherwise pale buff fur on the ventral side of the tail. The dorsal surface fluoresced pink in some otherwise light tan sections of fur. The skin inside the ears fluoresced white.

Order Rodentia

Rats and Mice. Family Muridae (7 species). Individuals of a black-footed tree rat (*Mesembriomys gouldii*; $n = 1$), a prehensile-tailed rat (*Pogonomys mollipeles*; $n = 1$) and giant white-tailed rat (*Uromys caudimaculatus*; $n = 2$) did not display the bright blue-white glow of the *Rattus* species' fur. In general, particularly at the shorter wavelengths, fur fluorescence was hardly perceptible. However, all three of these rat species showed some pink or orange fluorescence at the longer wavelengths. The black-footed tree rat had a pinkish wash over the head and shoulders and orange over the nape. The prehensile-tailed rat had a dusky pink fluorescence emanating from its russet brown dorsal fur. The giant white-tailed rats had some pink fluorescence on the face, mild pink brindling of fluorescence in the dorsal and flank fur, and some pale pink in the underfur of the flanks. The ventral side had a mild blueish white glow, and soft pale pink.

All three species of wild *Rattus* examined: the pale field rat (*Rattus tunneyi*; $n = 1$), bush rat (*R. fuscipes*; $n = 1$) and introduced black rat (*R. rattus*; $n = 2$) (Figure 3B); fluoresced bright blue-white all over, similarly at 365 nm and at 395–410 nm. At the longer excitation wavelength of 395–410 nm, the fluorescence of black rats turned a pale greenish blue. The pale field rat, bush rat and black rats all had wild-coloured brownish fur in white light. The dorsal areas of coats that had more melanin had the fluorescence subdued in those strands of fur. The fur of a native delicate mouse (*Pseudomys delicatulus*; $n = 1$) glowed bright blueish white all over, tempered by areas of melanin (Figure 3D). The blue tint was more evident at 365 nm than at longer wavelengths. The delicate mouse's fluorescence was similar in brightness and colour to that of *Rattus* spp. and *Antechinus* sp.

Order Chiroptera

Flying Foxes and Fruit Bats. Family Pteropodidae (3 species). At 365 nm excitation, spectacled flying foxes (*Pteropus conspicillatus*; $n = 2$) had a blue-grey fluorescence through their ginger collar, eye rings and flecked through the main fur. At 395–410 nm, the fluorescence turned more greenish grey, with the otherwise ginger fur giving a yellowish fluorescence. The fluorescence was quite subtle and was stronger on one female than

the other. A little red flying fox (*Pteropus scapulatus*; $n = 1$) had some grey fluorescence over the head at 365 nm. At 395–410 nm, the subtle fluorescence turned a brighter yellowy greenish grey over the head and the strip where the wings meet the ventral body surface. Eastern tube-nosed fruit bats (*Nyctimene robinsoni*; $n = 9$) had quite bright light-blue fluorescent fur with a distinct

glow on the ventral body and head, but mild grey on the dorsal body. Brightness of colour varied between individuals. The fluorescence was most intense at 365 nm (Figure 3C). The blue colour of the fur was more saturated than any other species. All yellow markings on the skin, including the wings, nose and ears, fluoresced bright neon yellow (Reinhold, 2022).

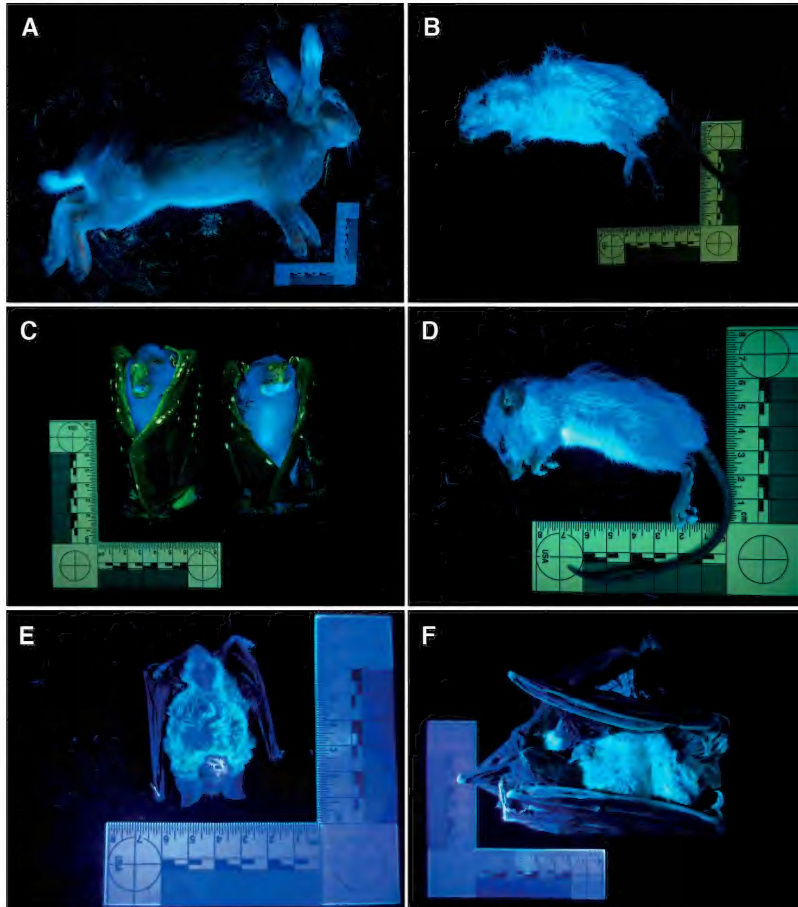


FIGURE 3. Fluorescence of Wet Tropics placental mammals. (A) European rabbit (introduced) male, fresh roadkill. Displaying mid-level white fluorescence on underside of tail and skin inside ear in 365 nm torchlight (10 s exposure). (B) Black rat (introduced) male, fresh suburban (poisoned?). Bright light-blue fluorescence in 365 nm (5 s). (C) Eastern tube-nosed fruit bats, male-female, frozen-thawed (from barbed wire fence). Bright yellow fluorescence of skin markings and blue fluorescence of fur in 365 nm (6 s). (D) Delicate mouse, female, frozen-thawed. Bright light-blue fluorescence all over in 365 nm (10 s). (E) Eastern horseshoe bat, male, frozen. Mid-to-bright pale green fluorescence of fur tips in 395–410 nm (3 s). (F) Ghost bat male, frozen. Mid-to-bright light-yellow fluorescence of fur in 395–410 nm (1 s).

Microbats. Family Vespertilionidae (10 species).

The ten species of microbat examined generally had minimal fluorescence of the fur, and none of the skin. Wing bones and claws often fluoresced. If discernible, fur fluorescence was usually very mild greyish or yellowish, and in the tips of the fur (diadem leaf-nosed bat (*Hipposideros diadema*; $n = 1$), large bent-winged bat (*Miniopterus orianae*; $n = 2$), eastern long-eared bat (*Nyctophilus bifax*; $n = 3$), forest bat (*Vespadelus* sp.; $n = 1$)). The wattled bats (Gould's wattled bat (*Chalinolobus gouldii*; $n = 1$), hoary wattled bat (*Chalinolobus nigrogriseus*; $n = 1$)) had no fluorescence of the fur, and that of the Ride's free-tailed bat (*Ozimops ridei*; $n = 2$) was only just perceptible. The northern free-tailed bat (*Ozimops lumsdenae*; $n = 1$) had mild pale pink fluorescence (only at 395–410 nm excitation) across the neck, turning to pale orange on the chest and flecked through the ventral fur. The eastern horseshoe bats (*Rhinolophus megaphyllus*; $n = 2$) displayed varying fluorescence of the fur, at only a low level in the female, but mid-to-bright in the male. The horseshoe bats' pale green to greenish yellow fluorescence was brightest throughout the tips of the ventral body fur, and when excited with the 395–410 nm wavelength (Figure 3E). The fluorescence extended onto fur visible on the face and lower patagium. The ghost bat (*Macroderma gigas*; $n = 1$) had faint pale pink fluorescence of the fur on the inner elbows, only at 395–410 nm excitation. The fur outlining the ears fluoresced mild light grey at 365 nm excitation, and light yellow at 395–410 nm excitation. A line of skin running vertically in the middle of each ear fluoresced mild white at 365 nm excitation, but there was no yellow of the skin. At 395–410 nm excitation, the ghost bat's dorsal body fur fluoresced only a mild pale green, but the ventral body fur and facial fur fluoresced mid-to-bright light yellow with a slight greenish tint (Figure 3F).

Order Carnivora

Dingo. Family Canidae (1 species). A young dingo (*Canis familiaris dingo*; $n = 1$) showed mild white fluorescence of the white fur at 365 nm excitation, but it was not as bright as that displayed by his paw pads and claws.

Discussion

Fluorescent fur is common in Wet Tropics mammals. Low-level or brighter fluorescence is a near-ubiquitous feature of fur as it is of most biological tissues (Stübel, 1911), and mid-level to strikingly bright fur occurred in 65% of 20 marsupial species and 41% of 22 placental species I examined. For the Wet Tropics bioregion at least, these findings refute a recent assumption that fur fluorescence is rare (Machemer, 2020; Anich et al., 2021; Olson et al., 2021). There is no reason to suspect that the Wet Tropics is a uniquely fluorescent bioregion for mammals, but fresh examples of the mammals of other bioregions have not been similarly surveyed. Rather than sporadically looking for brightly furred species, this systematic survey of available material, conducted in the context of a broader species assemblage, shows that fluorescent fur is not an anomaly, but the norm.

In a subset of mammals from Arkansas in North America, Tumilson & Tumilson (2021) found 19% of species to show bright fluorescence. However, it is difficult to compare subjective assessments of what constitutes brightness, with different excitation torches being used in different conditions. In other studies, unquantified issues of museum specimens fading and losing their fluorescence due to light exposure or wet preservation, or the addition of artificial fluorescence through taxidermy chemicals or fumigation, are also likely to confound comparisons between studies (Pohland, 2007; Reinhold, 2023; Toussaint et al., 2023). If live or freshly dead animals are examined, the true-to-life percentage of species with fluorescent fur may differ from museum-based studies.

While my sample size of mammal species did not approach that of the >1500 species for research on birds, Pohland (2007) found more than a third of parrot (Psittaciformes) species had fluorescent plumage parts, but only 12% of bird species worldwide fluoresced. These calculations for birds are far less than the 95% I found for mammals, or even the 50% that had noticeably mid-to-bright fluorescence of the fur. However, my finding that 95% of mammal species surveyed had fluorescent fur is equivalent to the 92% of frog species (172 out of 187) with fluorescent skin (Whitcher et al., 2023). In a comparison of terrestrial versus aquatic vertebrates, the 50% mid-to-bright statistic (22 out

of 44) for Wet Tropics mammals is greater than the obvious fluorescence in 41% (95 out of 230) of fish species in the upper 30 m of the water column on tropical coral reefs (De Brauwier et al., 2018). A generally held assumption that shallow marine environments harbour a greater percentage of fluorescent organisms than terrestrial ecosystems may have been based on the oversight that the latter had not been similarly surveyed.

Observations Conflicting with Accounts in the Literature

My observations of some species differed from some in the literature. For example, the fluorescence of the monotremes examined here and by Pine et al. (1985) and Reinhold (2020) was only subtle. However, both Anich et al. (2021) and Toussaint et al. (2023) reported conspicuous green/cyan fluorescence in dry-preserved platypus specimens, although relative brightness would need to be compared in the same conditions. Additionally, the green fluorescence I observed in the fur did not extend onto the skin. This is the only case where the fluorescence reported in the literature for preserved museum specimens was more vivid than that of fresh specimens. Conversely, the mild pink fluorescence I observed in platypus fur was not recorded by either Anich et al. (2021) or Toussaint et al. (2023).

The pale pink fluorescence I observed in the fur of introduced European rabbits was not noted by Stübel (1911). My observations of reddish fluorescence in the fur of common brushtail possums agreed with those of Bolliger (1944), but reddish colours were not recorded by Nicholls & Rienits (1971). Bolliger (1944) recorded long-nosed bandicoots (*P. nasuta*) as being non-fluorescent, whereas I found fresh specimens of northern long-nosed bandicoots that were strikingly bright pink. Whether this discrepancy is because of interspecies variation, the use of different excitation torches, preservation treatments or light exposure history is unknown. The extreme photolability of pink-red fluorescent colouration can make it difficult to detect (Pine et al., 1985; Hill, 2010).

Intraspecies Variation

The observed intraspecies variation of the intensity and coverage of pink fluorescence in bandicoots

invites further research, yet is likely to be confounded by fluorophore photodegradation. Bolliger (1944) found that newly regrown fur of common brushtail possums had a more vivid red, purple or pink fluorescence than the older adjacent fur. However, Olson et al. (2021) found that the pattern of patchiness of orange-red fluorescence over the pelage of African springhares (*Pedetes* spp.) seemed to be consistent within an individual over the space of more than a year. Generally, variation may indicate either different amounts of fluorophores being excreted at the follicle, or different light exposure histories in life. When the intensity of pink on the ventral surface of bandicoots differs, it indicates that perhaps that individual had more or less fluorophores in its fur initially (particularly for the white-fluorescent morph of northern long-nosed bandicoot). However, when variation occurs on the dorsal surface, incidental exposure to light is expected to confound the amount of fluorophores retained (Reinhold, 2023). The coverage and intensity of pink fluorescence had not varied noticeably within the same rainforest population of live northern long-nosed bandicoots (Reinhold, 2021). The lability of pink fluorescence, combined with small sample sizes, precluded analyses on age or sexual dimorphism.

Degradation of Older Roadkills and Unquantified Exposure of Freezer Specimens

Examining some freezer specimens with unknown origins, as I have done here, is expected to lead to false negatives of porphyrin fluorescence, as some will have been exposed to light. Exposure to sunlight affected pink fluorescence of roadkills, as observed by the pink occurring only on the dark-preserved side of animals if they had been exposed to the sun. Frozen specimens did not have any associated data regarding how much light they had been exposed to or which way up they were facing when they were found, but were sometimes only pink on one side. Roadkill specimens should be collected in the hours of darkness for a true-to-life account of fluorescence. Although nocturnal in life, the microbat specimens had probably been exposed to sunlight when found on barbed wire fences. Whether the lack of fluorescence in some frozen specimens was true to life, or a consequence of being exposed to light, cannot be known. However, the taxonomic consistency of

some of the non-pink observations, where some were fresh animals gathered at night, means that the observed lack of fluorescent porphyrins in the fur is likely to hold. Additionally, nocturnal species such as bush rats and striped possums have been observed live in the wild to only exhibit the bright blue-white fluorescence (Reinhold, 2021).

Observations of fluorescence in fur are expected to be further complicated by the condition of the specimens in freezers. Several species were examined only as frozen specimens, with no fresh or live animals found for comparison. Specimen degradation seemed to affect blue fluorescence to some degree. Old roadkill usually displayed fluorescence, but if a species had no comparison with fresh individuals, it cannot be known whether degradation had lessened the glow. Additionally, animals in which I could not detect fluorescence with the torches I used may have been fluorescent, but at other wavelengths or with stronger torches.

Nocturnality

A suggested correlation of fur fluorescence with nocturnality (e.g. Kohler et al., 2019; Olson et al., 2021) must be separated by fluorophore class. Due to the extreme photosensitivity of porphyrins (Galván et al., 2016), strong pink-red fluorescence is expected to be retained only in the fur of nocturnal species of mammal, unless it is shielded at the bases of the fur shafts. However, even if porphyrin pink fluorescence cannot be exposed to the sun without fading out, this does not imply a visual function of the molecules in nocturnal landscapes. Additionally, there is no evidence that the relatively photostable tryptophan-based fluorescence, of varying other colours, would be tied to nocturnality. Some familiar species with fluorescent pelage are diurnal (e.g. horses (*Equus caballus*), Posudin, 2007; and sheep, Collins, 1992).

Most Australian mammals are nocturnal (Van Dyck & Strahan, 2008). All placental mammal species examined here were nocturnal or nocturnal-crepuscular. This distribution does not allow for a comparison of fluorescence in the fur of nocturnal versus diurnal mammals, as was neatly done in the squirrel (Sciuridae) study (Kohler et al., 2019). The marsupials examined here were generally nocturnal and/or crepuscular, with the exception of antechinuses, red-legged pademelons

and black wallabies, which had diurnal tendencies (Menkhorst & Knight, 2011). These three species displayed fluorescence, one of them only at a low level, one at a mid level and one brightly so. Both monotreme species can be active day or night, with local populations of platypus being diurnal, but fur fluorescence was not bright. Fifty per cent of the primarily nocturnal species had noticeably mid-to-bright fluorescence, as did 50% of the primarily diurnal species. While strongly vivid porphyrin fluorescence can be found only in nocturnal mammals, examination of this subset of Wet Tropics species did not support the notion that fluorescence in general is tied to nocturnality.

Conclusion

The phenomenon of fluorescent fur is common and varied amongst the local mammal assemblage. Examination of Wet Tropics mammals has expanded our understanding of fluorescence in fur to the extent that we can expect it to occur at least in low levels in general, and with bright intensity reasonably often. This study fills in several pieces of the puzzle of fur fluorescence, but as a result, the puzzle appears more complex than it did with fewer data points. The observations of different fluorescent colours on the same species, activated by different wavelengths, further complicates categorisation. I could not isolate any factor to predict whether a species would have brightly fluorescent fur or not. In the Wet Tropics, bright blueish fluorescence occurred similarly in the fur of small, mostly insectivorous semi-arboreal antechinuses, mostly herbivorous ground-dwelling rodents, larger tree-dwelling marsupials that were insectivorous or folivorous, and mostly frugivorous bats. Bright pink fluorescence occurred in varied taxa from ground-dwelling omnivorous bandicoots to semi-arboreal carnivorous quolls to the mostly folivorous tree-dwelling brushtail possums. From this study, combined with what is known so far from the literature, it seems unlikely that patterns of fluorescent fur can be easily correlated to broader phylogenies, or habitat or lifestyle parameters. Brightly fluorescent fur is found in a varied array of mammals, from bats to kangaroos, and even the inclusion of many more taxa may not draw any kind of conclusions without studying the metabolic pathways involved.

Appendix 1

Wet tropics mammal specimens examined for fur fluorescence. Observations taken directly from carcasses. Skin not noticeably fluorescent unless specified. 'Fresh' means within 24 hours of death. Animals were adult-sized unless specified. Size may be indicated in different ways, depending on parts of the animal that were accessible due to damage. HL = head length; HB = head-body length; TL = total length; FA = forearm length; PY = pouch young; QM = Queensland Museum.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Monotremes (Order: Monotremata. Families: Ornithorhynchidae and Tachyglossidae)			
Platypus (<i>Ornithorhynchus anatinus</i>) ? Whole animal to QM.	QPWS. Frozen.	None discernible.	Ventral: yellowish green. Dorsal: some moss green. Subtle.
Platypus (<i>Ornithorhynchus anatinus</i>) ♀	JCU. Frozen-thawed.	Mild silvery grey throughout fur, especially on flanks above hindquarters. Not as strong on dorsum as on ventrum; none on tail. Brighter at 365 nm than at 310 nm. Bill whitish.	Dorsal: faint moss green flecked with strands of pale green. Less on tail. Ventral: brighter pale green-grey over lower flanks and back legs. Pale green is in the tips of the fur – underfur reflects. Bill whitish. Clipped flank fur: some orangey-pink whole strands in otherwise light-brown fur. Some pale and dusky pink in distal half of thicker strands, and pale pink in distal half of otherwise light-brown underfur. Not in grey underfur. Very mild and not evident at the whole-pelt level.
Short-beaked echidna (<i>Tachyglossus aculeatus</i>) ?	Roadkill. Fresh, night.	Not as discernible as at 380–410 nm.	Dorsal and neck fur: similar moss green as platypus. Ventral fur: greeny yellow. Very dull. Spines: pale greenish yellow, as strong as expected from keratin content, but not bright.
Short-beaked echidna (<i>Tachyglossus aculeatus</i>) ?	Roadkill. Fresh, dawn. Ventral exposed to 1 hr early overcast.	Not discernible in fur. Blue skin near cloaca.	Very dull moss-green fur, mostly on tops of front paws. Greenish yellow spines. Blue skin towards cloaca.
Marsupials			
Quolls, antechinuses and dunnarts (Order: Dasyuromorphia. Family: Dasyuridae)			
Rusty(?) antechinus (<i>Antechinus adustus</i> (?)) ♂ Whole animal to QM.	QPWS. Frozen.	Blue-white all over in underfur; tips remain brown.	Not as bright as at 365 nm.
Rusty(?) antechinus (<i>Antechinus adustus</i> (?)) ♂ Whole animal to QM.	JCU. Frozen-thawed.	Blue-grey-white through fur, mostly in underfur, but fur also absorbing.	A little yellowish white, but mostly absorbing. Slight pink wash around rump.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Northern quoll (<i>Dasyurus hallucatus</i>) ♀ Young adult. Whole animal to QM.	QPWS. Frozen.	Spots fluoresce white; ventrum remains cream.	Strong dark pink over face, chin, neck, flank, hindquarters and back feet. Left flank but not right flank. Not dorsal surface of head or body. Not photographed.
Northern quoll (<i>Dasyurus hallucatus</i>) ♂	QPWS. Frozen.	Spots fluoresce white, base of tail orange, shoulders green. Chest patch greenish white.	Spots fluoresce white, base of tail orange, shoulders green. Chest patch greenish white. Ventrums and feet pink.
Northern quoll (<i>Dasyurus hallucatus</i>) ♂ Whole animal to QM.	QPWS. Frozen.	Spots, neck and ventrum.	Spots, neck and ventrum. Slight pink-orange wash over feet.
Northern quoll (<i>Dasyurus hallucatus</i>) ♂ Whole animal to QM.	QPWS. Frozen.	Spots white, genital fur white.	Greenish on side of neck.
Northern quoll (<i>Dasyurus hallucatus</i>) ♂ Whole animal to QM.	QPWS. Frozen.	Spots white, white around genitals, yet ventral fur remains cream.	Slight pink wash around edge of ventrum and inside legs.
Northern quoll (<i>Dasyurus hallucatus</i>) ♂	JCU. Frozen-thawed.	Spots white, wash of orange over tops of paws, mild.	Bright pink through brown flank fur and white spots. Right flank but not left flank. On white spots, bright pink evident all along strands, but some white at tips. Pink on top of all paws and over head, and pink wash along ventral edge.
Northern quoll (<i>Dasyurus hallucatus</i>) ♂	JCU. Frozen-thawed.	Spots white as in previous specimen.	Pink fluorescence absent.
Northern quoll (<i>Dasyurus hallucatus</i>) ♂ Whole animal to QM.	JCU. Frozen.	Spots slightly white. Feet orange. Wash of orangey pink over chest and thighs.	Bright pink on cheek, in front of ears and on neck. Orangey pink on forearms and ankles. Some patches of bright strong pink in underfur of right flank, especially basal 2/3 of white spots. Bright floss pink on ventral fur, testes, feet, under tail and cheek. On ventral fur, the fairy floss pink is on the pale fawn distal half of strands, but reflects light on the darker brown proximal half.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Northern quoll (<i>Dasyurus hallucatus</i>) ♂	Roadkill. Fresh, right/ventral exposed to 8 hrs shade and sun.	Spots mild white. Chest patch lemon yellow. Pale pinky orange between back thighs and genital area.	Sides of neck quite bright light-yellowish green (green neck fluorescence on both sides even though one side was exposed to sun). Chest patch bright lemon yellow. Spots not so white. Spots and brown fur on left flank (not right flank) strong pink. Face dark pink. Bright fairy floss pink between back legs and genitals. Underfur dark pink, including tail.
Dunnart (<i>Sminthopsis</i> sp.) ♂ Whole animal to QM.	QPWS.	Minimal.	Ventrum whitish. Tips of fur pale pink on dorsum.
Bandicoots (Order: Peramelemorphia. Family: Peramelidae)			
Northern brown bandicoot (<i>Isodon macrourus</i>) ? Smallish.	Roadkill. Fresh, ventral exposed to 8 hrs sun.	Weaker than at 380–410 nm.	Orange/pink and yellow dorsum, but only mid level. Ventral fur not fluorescent except for pink patch on chest that was covered by forearm, and along edge of dorsum.
Northern brown bandicoot (<i>Isodon macrourus</i>) ? HL=90 mm.	Roadkill. Fresh, dawn.	Dorsal: yellow. Flanks: stunning pink. Ventral: orangey pink. Head: strands have pink base and yellow tips.	Dorsal: yellow, particularly in tips. Flank: very pink. Ventral: strong orangey pink.
Northern brown bandicoot (<i>Isodon macrourus</i>) ? Smallish.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal: yellow tips. Less so than rest of body. Flank: bright pink underneath. Ventral: bright pink.
Northern brown bandicoot (<i>Isodon macrourus</i>) ♂ Smallish, small testes.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal: darker on top – bright magenta pink showing through underneath, yellow tips. Ventral: very bright pink. Head: pink more pronounced around neck.
Northern brown bandicoot (<i>Isodon macrourus</i>) ♂ Smallish, small testes.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal: darker, but bright pink underneath and yellow tips. Flank: mottled bright magenta pink. Ventral: bright pink. Head: particularly pink on neck. Fine short fur under base of tail fluorescent white.
Northern brown bandicoot (<i>Isodon macrourus</i>) ♂ HL=87 mm.	Roadkill. Fresh, dawn.	Not really fluorescent at 310 nm. Dorsal: yellow/tan tips, dark mid-section and bright pink base of strands. Bright pink and yellow. Ventral: bright orange/pinky orange.	Dorsal: darker pink, more prominent than yellow, brindled. Especially pink on top of feet. Flank: magenta pink. Ventral: very bright pink, particularly bright under chin.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Northern brown bandicoot (<i>Isodon macrourus</i>) ♂ Full-size testes. HL=105.4 mm. Head to QM.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal and flank: mild yellow, brindled with some pink. Ventral: bright pink.
Northern brown bandicoot (<i>Isodon macrourus</i>) ♂ Small-medium testes.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal and flank: mild yellow, brindled with some pink, but not so much. Ventral: bright pink.
Northern brown bandicoot (<i>Isodon macrourus</i>) ♀ Small, virginal.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal and flank: mild yellow, brindled with some pink. Ventral: bright pink.
Northern brown bandicoot (<i>Isodon macrourus</i>) ♀ Largish, pouch developed.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal and flank: some magenta pink guard hairs, and yellow. Ventral: bright pink.
Northern brown bandicoot (<i>Isodon macrourus</i>) ♂ Full-size testes. HL=102.8 mm. Head to QM.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal and flank: mild yellow brindled with some pink. Ventral: bright pink.
Northern brown bandicoot (<i>Isodon macrourus</i>) ♀ Pouch developed. HL=86.1 mm.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal and flank: brindled pink and yellow. Ventral: bright pink.
Northern brown bandicoot (<i>Isodon macrourus</i>) ♀ Virginal.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal: some pink in underfur, and yellow tips. Flank: some pink in underfur. Ventral: bright pink.
Northern brown bandicoot (<i>Isodon macrourus</i>) ? Mid-sized.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal: brindled pink and yellow. Flank: bright pink brindled with yellow. Ventral: bright pink. Head: patches of bright pink.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Northern brown bandicoot (<i>Isoodon macrourus</i>) ♂ Mid-sized.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Dorsal and flank: bright pink brindled with yellow. Ventral: bright pink, lighter.
Northern brown bandicoot (<i>Isoodon macrourus</i>) ♂ Mid-sized, full-size testes. HL=98.2 mm.	Roadkill. Fresh, dawn.	Less than at 380–410 nm.	Very bright pink. More so in patches concentrated around the neck. Less so over dorsal body.
Northern brown bandicoot (<i>Isoodon macrourus</i>) ? Mid-sized.	Roadkill. Fresh, dawn.	Same as at 380–410 nm, but less so.	Dorsal: brindled pink and yellow. Flank: magenta pink and yellow brindled. Ventral: bright pink. Head: magenta pink cheeks.
Northern brown bandicoot (<i>Isoodon macrourus</i>) ♂ Large. HL=99.7 mm.	Roadkill. Fresh, dawn.	Dorsal: some brindled pink. Flank: brindled pink and yellow – orange. Ventral: pink/orange.	Dorsal: brindled orange/pink. Flank: orange/pink. Ventral: orange/pink. Head: face bright magenta pink, magenta behind ears.
Northern brown bandicoot (<i>Isoodon macrourus</i>) ♀ HL=89 mm. + 3 pinky PY: HL=20 mm.	Roadkill. Fresh, dawn.	Not at 310 nm. Dorsal and flank: mixture of blue-white, bright pink and paler orange/yellow. Ventral: bright white as well as pale pink on different strands of fur.	Dorsal and flank: white much less so, and pink much stronger and darker. Pink very, very strong. In individual strands, pink on lower 2/3, then short section of dark, then pale pink/yellow tip. Ventral: white present but less so and more absorbing. Incredibly strong neon pink. Some pink strands have white at the very tips.
Northern brown bandicoot (<i>Isoodon macrourus</i>) ♂ Smallish. HL=84.2 mm.	Roadkill. Fresh, night.	Less than at 380–410 nm.	Dorsal: thickest strands (otherwise wholly white) are hot pink peppered through fur. More yellow. Flank: hot pink throughout, brindled with yellow. Ventral: incredibly bright neon pink. The brightest pink is in the thicker fur (ventral), lacking at base where it is otherwise grey, but wholly pink for distal 4/5. Head: only really on cheeks. Brightest neon pink northern brown bandicoot observed.
Northern brown bandicoot (<i>Isoodon macrourus</i>) ♀ HL=91.4 mm. + 1 ♀ furred PY: HL=33.6 mm.	Roadkill. Fresh, night.	Dorsal: mostly absorbing. Flank: not blue. Ventral: orangey pink.	Dorsal: mostly not fluorescent, but has yellow, and some pink on the rump. Flank: bubblegum pink lower down. Ventral: bubblegum pink. Especially in whole strands of thick fur. Head: pink around eyes, anterior cheeks and under chin. Joey reflecting purple light.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Northern brown bandicoot (<i>Isoodon macrourus</i>) ?	Roadkill. Fresh, dawn.	Mid orange-pink, especially venter.	Bright pink all over, more on venter.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♀ HL=83.9 mm. + 2 PY: HL=30 mm.	JCU. Frozen-thawed.	At 310 nm: not really fluorescent. At 365 nm: Dorsal: pinky orange strands flecked through fur. Flank: more pinky orange strands. Ventral: orangey pink.	Much brighter pink than at 365 nm.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♂ Largish. HB=320 mm.	Roadkill. Fresh, dawn.	Dorsal and flank: strands remaining grey/black for proximal 3/4, pink tips. Ventral: white with pink wash. Head: pink on cheek. White around neck.	Dorsal and flank: mottled with whole strands of pink, rest remaining black. Underfur remains grey. Pink patchy. Ventral: white with pink wash. Head: strongest. Pink cheek. White under neck.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ? Largish.	Roadkill. Fresh, dawn.	At 310 nm: not really fluorescent. At 365 nm: Dorsal: mottled pink, white prominent in tan fur. Flank: some strands pink, some remaining grey at base and turning pink at top; some have yellow tips. Ventral: white with pink wash. Head: blueish white to whitish, more pink at back.	Dorsal: pink most prominent on hindquarters. Flank: base of strands remains soft grey; top half fluoresces pink. Ventral: white with strong pink wash.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♀ Small, virginal.	Roadkill. Fresh, ventral right exposed to 1.5 hrs early sun.	Dorsal: strands have pink base with yellow tips. Flank: pink. Ventral: white.	Dorsal: intense pink with yellow tips. Flank: intense pink. Ventral: white with pink wash.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♂ Small testes, HL=87.9 mm.	Roadkill. Fresh, night.	Less than at 380–410 nm.	Dorsal and flank: magenta at base; yellow at tips. Ventral: wildly vivid orangish pink. Head: pink cheeks and around eyes. Most strongly vivid fluorescence of any animal observed.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♀ Small, virginal. TL=350 mm.	Roadkill. Fresh, night.	Less than at 380–410 nm.	Dorsal: base of strands pink, brindled with yellow and brown. Flank: bright orangey pink. Ventral: white washed with pink tips. Head: bright orangey pink, particularly at the sides. As bright pink as the previous specimen.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♂ Full-size testes. HL=120.3 mm Pale flanks, banded. Head to QM.	Roadkill. Fresh, night.	At 310 nm: not fluorescent. At 365 nm: Dorsal: mostly remaining dark, but some pink strands. Flank: brindled bright orangey pink with bands that are black or white. Ventral: white, pink tinge. Distinct white fluorescence on otherwise buff fur. Head: deep orange-pink, particularly red ring around eye.	Pinks turned brighter hot pink than at 365 nm. White also bright.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♂ Full-size testes.	Roadkill. Fresh, night.	At 310 nm: not fluorescent. At 365 nm: Dorsal: mostly remaining black and tan, only some strands orangey pink. Flank: orangey pink brindled in with otherwise brownish fur. Other strands remaining white or black. Ventral: white with orange-pink wash. Distinct white fluorescence on otherwise buff fur. Head: corresponded to dorsal and flank parts of rest of body.	Much brighter pink – hot pink – than at 365 nm, covering more of the white-fluorescing area. White also bright.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♂ Smallish testes.	Roadkill. Fresh, ventral left exposed to 2 hrs early sun.	At 310 nm: Mild white fluorescence on otherwise buff flank and ventral fur. At 365 nm: Dorsal: mostly absorbs, but some pink strands of otherwise buff fur. Flank: white fluorescence on otherwise buff fur. Light pink and orange on other fur. Ventral: white fluorescence quite pronounced on more than half of fur; rest absorbs.	Dorsal: mostly strong pink and magenta. Some whole strands, and other strands with fluorescing and absorbing sections. Tips pale orange. Flank: white fluorescence present, but less than at 365 nm. Very vivid bright strong dark pink. Ventral: some parts mild white. Fur that absorbed at 365 nm is now pale pink. Flank and dorsal have much stronger bright pink fluorescence than ventral.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♂ Mid-sized, full-size testes. HL=89 mm.	Roadkill. Fresh, night.	Orange/pink much duller than at 380–410 nm, but white fluorescence mid-strength.	Dorsal: pink, but darker brindled than rest of body. Flank: brindled pink and yellow. Ventral: white underneath with bright pink tips mixed with wholly pink strands.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♂ Full-size testes. HL=116.5 mm.	Roadkill. Fresh, night.	Dorsal: some pink. Flank: white through flank as well as pink, though mottled. Ventral: prominent white fluorescence.	Dorsal: some pink. Flank: bright pink, but patchy. Ventral: white fluorescence, only tinged with pink. <i>Note:</i> long-nosed have shorter ventral fur, and less of it, than northern browns.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♂ Full-size testes. HL=111.6 mm. Pale flanks, some banding.	Roadkill. Fresh, night.	Dorsal: mostly yellow. Some pink and blue-white. Very orange and yellow on rump. Yellow more so at 365 nm than at 380–410 nm. Flank: blueish white, interspersed with dark pink. Ventral: uniform bright blueish white, only a hint of pink. Head: blueish white on top of head, neck and side of face.	Dorsal: dark, but yellow and pink fluorescence more so towards rump. Rump the strongest bright pink, mixed with yellow, making it look orange at some angles. Flank: both white and bright pink fluorescence. Ventral: pure white with just flushes of pale pink on some strands. Head: pink around eye and snout. Rest white peppered with black.
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♀ Small, virginal. HL=83.0 mm.	Roadkill. Fresh, night.	Dorsal: more yellow brindled with absorbing brown fur. Flank: orangey pink, particularly strong orange on rump. Ventral: orangey pink in tips, white in base. Head: blueish white on neck. Orangey pink side of face.	Dorsal: bright pink and yellow brindled with absorbing brown fur. Flank: very strong pink, particularly strong and orangey on rump, much more so than the next specimen. Ventral: bright pink in longer thicker strands; white in shorter softer strands. Head: pink on side of face.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Northern long-nosed bandicoot (<i>Perameles pallescens</i>) ♀ Small, virginal. HL=80.2 mm. One dark band on paler flanks.	Roadkill. Fresh, night.	Dorsal: more yellow brindled with absorbing brown fur. Flank: orangey pink, and on rump. Ventral: flushes of orangey pink, also white.	Dorsal: brindled yellow and pink. Flank: bright pink flanks, thighs and rump. Ventral: bright pink on whole strands, some strands white, many pink at tips and white at base.
Wallabies and possums (Order: Diprotodontia)			
Wallabies, tree-kangaroos and pademelons (Family: Macropodidae)			
Agile wallaby (<i>Notamacropus agilis</i>) ♂ Young at heel.	Roadkill. Fresh, night (streetlights).	At 310 nm: Purplish glow on muzzle. Dorsal and ventral: mild light blue. Flank: light blue. At 365 nm: Dorsal and flank: mostly absorbing. Ventral: mild white glow to white parts of fur.	Dorsal and flank: mostly absorbing, but mild white fluorescing strands scattered throughout fur. Ventral: mild white glow to white parts of fur. White ventral fluorescence similar to that of rabbit, but less so.
Swamp wallaby (<i>Wallabia bicolor</i>) ?	Roadkill. Decaying, left flank exposed to ~days sun.	At 310 nm: just pale grey. At 365 nm: Dorsal and rump: some light grey, maybe from white strands. Mostly remains dark. Ventral: faint white glow over lighter fur.	Dorsal and rump: light greyish and yellowish, but very faint. Ventral: paler fur turns slightly yellowish. At 380 nm, turns quite green-yellow, but not much glow.
Swamp wallaby (<i>Wallabia bicolor</i>) ♂	Roadkill. Fresh, right flank exposed to 2.5 hrs sun and shade.	At 310 nm: Dorsal and flank: absorbing and light-purple fluorescence. Ventral: absorbing and more light purple. At 365 nm: Dorsal and flank: maybe very slight yellowish. Ventral: absorbing and purple.	Dorsal: yellowish tips. Some blue-grey strands. Flank: mostly absorbing. Ventral: strongly absorbing.
Lumholtz's tree-kangaroo (<i>Dendrolagus lumholtzi</i>) ♂	JCU. Frozen-thawed.	Quite bright pale blue in the underfur all over. Pale blue in fur shafts until brown on tips. Tail not fluorescent apart from base.	Not nearly as evident as with 365 nm.
Lumholtz's tree-kangaroo (<i>Dendrolagus lumholtzi</i>) ♂	JCU. Frozen-thawed.	Same fluorescence as the specimen above: pale blue in underfur.	Not nearly as evident as with 365 nm.
Red-legged pademelon (<i>Thylogale stigmatica</i>) ♂ Full-size testes.	Roadkill. Fresh, dorsal exposed to 1.5 hrs shade.	At 310 nm: Dorsal: pale grey fur fluoresces white; rest absorbs or reflects. Flank: pale grey reflects purple, and brown absorbs. Ventral: faint white fluorescence of pale fur. At 365 nm: Dorsal: some white fluorescence of otherwise pale grey fur. Mostly reflecting; brown fur absorbs. Flank: pale grey fur turns light purple. Brown fur absorbs. Ventral: a little white.	Dorsal: white fluorescence less. Yellow tips prominent. Flank: absorbs, but some otherwise yellowish tan fur fluoresces pink. Ventral: very slight pink where otherwise pale grey at base of some strands.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Red-legged pademelon (<i>Thylogale stigmatica</i>) ♂ Subadult, smallish testes.	Roadkill. Fresh, dawn.	At 310 nm: Flank: purple on grey underfur; absorbing on brown outer fur. At 365 nm: Flank: very strong light-purple fluorescence on otherwise grey fur; brown absorbing.	Flank: grey fur turns purple-grey with pink at the bases of some strands. Brown fur absorbing, but subtle pink through some of the tips.
Red-legged pademelon (<i>Thylogale stigmatica</i>) ♂ Young at heel, small testes.	Roadkill. Fresh, dawn.	At 310 nm: Dorsal: very mild white on otherwise light-grey underfur. Flank: light purple/grey in otherwise grey fur; absorbing in brown fur. Ventral: Mild blue-white glow on pale buff fur; rest absorbing. At 365 nm: Dorsal: light purple on grey underfur. Absorbing on brown fur. Flank: purplish grey in grey fur. Absorbing in brown fur. Ventral: quite bright blue-white glow on pale buff fur; absorbing on darker fur.	Dorsal: mostly absorbing, but tips of fur have slight pink tinge. Flank: same as dorsal, but dusky pink fluorescence more ubiquitous throughout light-brown fur tips. Ventral: very mild white glow. Very slight pale pink wash in some of the otherwise pale brown fur.
Bettongs (Family: Potoroidae)			
Rufous bettong (<i>Aepyprymnus rufescens</i>) ♂ Full-size testes. HL=93.8 mm.	Roadkill. Fresh, dorsal exposed to 3.5 hrs overcast shade.	At 310 nm: no fluorescence. At 365 nm: Dorsal: blueish white. Flank: more blueish white, brightest on hindquarters. Some pink. Ventral: white and light pink.	Dorsal: dark pink strands, but many white tips remain white. Flank: patches of stronger and brighter pink. Whole strands, but darker towards the tips. Ventral: most pink, whole strands in uniform fairy floss pink.
Rufous bettong (<i>Aepyprymnus rufescens</i>) ?	Roadkill. Decaying, right flank exposed to >1 day sun.	Fluorescence brightest on rump. At 310 nm, underfur glows faint purplish white. At 365 nm, underfur glows light purplish white. Brown fur absorbs.	Fluorescence only evident on rump fur. Underfur faint blueish grey, but hardly discernible.
Rufous bettong (<i>Aepyprymnus rufescens</i>) ♀ + 1 ♂ pinky PY.	Roadkill. Fresh, left flank exposed to 8 hrs sun.	At 310 nm: mostly absorbing. At 365 nm: Dorsal: some greyish white strands flecked through, very little. Flank: some pale pink whole strands and in softer fur. Ventral: mild white glow.	Dorsal: darker pink at fur bases; white at tips. Flank: good pink fluorescence – mid-level pink. In whole otherwise whitish strands, and through softer fur. Quite uniform mid pink. Ventral: mild mid-white glow. Strongly absorbing.
Northern bettong (<i>Bettongia tropica</i>) ♂ HL=88.4 mm. Whole animal to QM.	JCU. Frozen.	Slightly grey-white, more so at 310 nm than at 365 nm.	Dorsal and flank: no fluorescence perceptible; just reflecting. Ventral: very small patches of pale salmon pink in distal half of fine fur.
Northern bettong (<i>Bettongia tropica</i>) ? HL=92.6 mm. Whole animal to QM.	JCU. Frozen.	No fluorescence perceptible.	Dorsal, flank and ventral: no fluorescence perceptible. Head: some salmon pink in left cheek fur – in whole strands of fur, and adjacent fur has dark pink in basal half.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Northern bettong (<i>Bettongia tropica</i>) ? HL=86.4 mm. Whole animal to QM.	JCU. Frozen.	No fluorescence perceptible.	Dorsal, flank and ventral: no fluorescence perceptible. Head: some pale pink in right cheek in distal parts of fur.
Northern bettong (<i>Bettongia tropica</i>) ♀ Whole animal to QM.	JCU. Frozen.	At 310 nm: not really fluorescent. At 365 nm: otherwise buff fur tips maybe turn a little yellow.	Dorsal and ventral: no fluorescence perceptible. Flank: pink wash along whole strands in lower flank fur. Head: fur on inside of right ear (otherwise pale buff) fluoresces mild green-blue-white at 365–410 nm.
Northern bettong (<i>Bettongia tropica</i>) ♂ Whole animal to QM.	JCU. Frozen.	Fluorescence minimal.	Pink throughout fur; can be distal half or proximal half, some stronger. Pale buff-white tips mostly remain white. Pinkest on head, neck, flank, rump and base of tail. In rump and flank fur, light pink is more in distal half, whereas in dorsal fur the white tips remain white more. Yellow on ventral side of tail, but not as pronounced in this specimen.
Northern bettong (<i>Bettongia tropica</i>) ♂ Whole animal to QM.	JCU. Frozen.	Fluorescence minimal.	Some pink on whole strands at forearms and ankle. Brighter at rump.
Northern bettong (<i>Bettongia tropica</i>) ♂ Whole animal to QM.	JCU. Frozen.	Fluorescence minimal.	Pink throughout head, face, dorsal, flank, hindquarters, legs, tail and neck. Pink on neck is through distal half of strands, but not on white tips. Pink mottled throughout flank, broken up by white tips. Pink not on ventral, apart from edges and between thighs. Ventral half of tail fur (otherwise light brown) fluoresces mild greenish yellow.
Northern bettong (<i>Bettongia tropica</i>) ♂ Whole animal to QM.	JCU. Frozen.	Fluorescence minimal.	Mid-light pink in distal half of paler buff fur on head, face, neck, legs, flank and dorsal – some darker pink in proximal half of fur and whole strands. Pink on rump and base of tail, and some down dorsal tail. Not so much on ventral. Distal tips perhaps a little yellow over dorsal. Mottled.
Northern bettong (<i>Bettongia tropica</i>) ♂ Whole animal to QM.	JCU. Frozen.	Fluorescence minimal.	Light pink in whole strands and distal half of fur at face, neck, flank, ventral, dorsal, leg, rump and base of tail fur.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Gliders and striped possums (Family: Petauridae)			
Striped possum (<i>Dactylopsila trivirgata</i>) ?	Roadkill. Decaying, ventral/right exposed to ~days sun.	At 310 nm: appears charcoal black and neon white, but not bright. At 365 nm: black stripes remain black. White stripes brilliant neon white/greenish blueish white. Ventral fur cream. Tail tip same as rest of tail.	White stripes more white than neon. Ventral fur very bright cream. Some strands yellowish cream; some strands pure white.
Striped possum (<i>Dactylopsila trivirgata</i>) ♂	JCU. Frozen-thawed.	At 310 nm: decent white glow over white stripes and ventral fur. Pale grey on intermediate fur. At 365 nm: remarkable blueish white glow on white stripes and ventral fur, and pale grey on intermediate fur. Tail tip lacks the vivid blue-white glow.	White glow, but not as distinct as at 365 nm. Almost greenish tint to the glow.
Striped possum (<i>Dactylopsila trivirgata</i>) ♂ Full-size testes. HL=64.0 mm.	JCU. Frozen-thawed.	Same as specimen above.	Same as specimen above.
Striped possum (<i>Dactylopsila trivirgata</i>) ♂ HL=61.2 mm.	JCU. Frozen-thawed.	Same as specimen above.	Same as specimen above.
Striped possum (<i>Dactylopsila trivirgata</i>) ♂ HL=64.4 mm.	JCU. Frozen-thawed.	Same as specimen above.	Same as specimen above.
Striped possum (<i>Dactylopsila trivirgata</i>) ♂ HB=260 mm.	JCU. Frozen-thawed.	Same as specimen above.	Same as specimen above.
Striped possum (<i>Dactylopsila trivirgata</i>) ♂ Full-size testes. HL=69.5 mm.	JCU. Frozen-thawed.	Same as specimen above.	Same as specimen above.
Striped possum (<i>Dactylopsila trivirgata</i>) ♂ HL=64.8 mm.	JCU. Frozen-thawed.	Same as specimen above, but particularly bright fur.	Same as specimen above, but particularly bright fur.
Striped possum (<i>Dactylopsila trivirgata</i>) ?	JCU. Frozen-thawed.	Only striped possum that did not glow – very degraded.	Only striped possum that did not glow – very degraded.
Kreff's glider (<i>Petaurus notatus</i>) ♂ Whole animal to QM.	QPWS. Frozen.	Dorsal: pale blueish all over. Ventral: white. More evident at 310 nm than at 365 nm.	Slight yellowish.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Kreff's glider (<i>Petaurus notatus</i>) ♂ HL=35.8 mm.	JCU. Frozen-thawed.	At 310 nm: Dorsal: blueish white fluorescence over the whole fur. Ventral, head and face: blueish white glow. At 365 nm: Dorsal: milder blueish white. Ventral: not really.	Dorsal: not really fluorescent. Ventral: mild dusky pink colour over entire fur. Edges stand out as absorbing.
Kreff's glider (<i>Petaurus notatus</i>) ♀ Pouch developed. HL=38.9 mm.	JCU. Frozen-thawed.	Same as specimen above, but no blueish white glow on face and head.	Same as specimen above.
Kreff's glider (<i>Petaurus notatus</i>) ♀ Pouch developed. HL=42.2 mm.	JCU. Frozen-thawed.	Same as specimen above (no blueish white glow on face and head).	Same as specimen above.
Feathertail glider (Family: Acrobatidae)			
Feathertail glider (<i>Acrobates pygmaeus</i>) ♀ Whole animal to QM.	QPWS. Frozen.	Not discernible.	Slight apricot pink to face and ventrum.
Ringtail possums and greater gliders (Family: Pseudocheiridae)			
Northern greater glider (<i>Petauroides minor</i>) ?	JCU. Frozen.	At 310 nm: Dorsal: slight pale grey. Ventral: white. At 365 nm: Dorsal: stronger pale grey. Ventral: stronger white.	Dorsal: mostly reflecting. Ventral: mostly reflecting, but white chest absorbing. No pink.
Northern greater glider (<i>Petauroides minor</i>) ?	JCU. Frozen.	Same as specimen above, with some white fluorescence on white patch under tail.	Same as specimen above, with a little fluorescence of white under tail. No pink.
Green ringtail possum (<i>Pseudocheirops archeri</i>) ♀ Whole animal to QM.	QPWS. Frozen.	Minimal.	White along middle of ventrum. Pink wash at edges of ventrum. Dull pinkish orange inside legs and under tail. Flecks of white fur turn white or pale green.
Green ringtail possum (<i>Pseudocheirops archeri</i>) ?	JCU. Frozen.	Mild white on the white fur. Pale yellow scattered throughout.	Nothing really glowing; white fur a little, and yellow tips very mild.
Green ringtail possum (<i>Pseudocheirops archeri</i>) ?	JCU. Frozen.	Same as specimen above.	Same as specimen above.
Green ringtail possum (<i>Pseudocheirops archeri</i>) ?	JCU. Frozen.	Same as specimen above.	Same as specimen above.
Green ringtail possum (<i>Pseudocheirops archeri</i>) ?	JCU. Frozen.	Same as specimen above.	Same as specimen above.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Green ringtail possum (<i>Pseudochirops archeri</i>) ♀	JCU. Frozen.	Same as specimen above.	Same as specimen above.
Green ringtail possum (<i>Pseudochirops archeri</i>) ?	JCU. Frozen.	Same as specimen above.	Same as specimen above.
Green ringtail possum (<i>Pseudochirops archeri</i>) ?	JCU. Frozen.	Same as specimen above.	Same as specimen above.
Green ringtail possum (<i>Pseudochirops archeri</i>) ?	Roadkill. Flattened, dorsal exposed to >1 day shade and sun.	At 310 nm: Dorsal: none. Flank: mild white of pale brown fur parts. Ventral: mild white. Tail: very mild grey/white on pale grey fur parts. At 365 nm: Dorsal: yellow tips fluoresce white. Some pale grey fur fluoresces pale pink. Flank: yellow tips turn blueish white. Ventral: mostly stronger white fluorescence. Darker fur absorbing. Tail: grey/white fluorescence throughout with a little dusky pink and tips pale green/yellow.	Dorsal: mostly reflecting, apart from yellow tips which are absorbing and fluorescing pale greeny-yellow white. Patterning is more distinctive in UV than in white light. Flank: tips appear bright pale greeny yellow. Some tufts of dusky pink fur in pale grey/brown underfur. Ventral: mostly absorbing, except pale buff parts that were absorbing at shorter wavelengths are now pale pink. Also white fluorescence, but milder than at shorter wavelengths. Tail: tips pale yellow. Dusky pink throughout on pale brown fur. Rest absorbing.
Green ringtail possum (<i>Pseudochirops archeri</i>) ♂ Whole animal to JCU.	Roadkill. Fresh, night.	Same as for 380–410 nm. Not so much at 310 nm.	Dorsal: stripes stand out more (yellow) in UV than in white light. Ventral: white. Head: white ear patches.
Herbert river ringtail possum (<i>Pseudochirulus herbertensis</i>) ♀ Whole animal to QM.	QPWS. Frozen.	Ventral cream fur turns only slightly white.	Cream flank fur and top of legs have pink wash in basal half of fur.
Herbert river ringtail possum (<i>Pseudochirulus herbertensis</i>) ♀ Whole animal to QM.	QPWS. Frozen.	Not discernible. [Less cream fur on this individual.]	Pale greenish to tips of fur all over excepting tail. No pink.
Herbert river ringtail possum (<i>Pseudochirulus herbertensis</i>) ♂	JCU. Frozen.	At 310 nm: Dorsal: faint grey. Ventral: white glow. White glow also same on white fur that goes up over shoulders. At 365 nm: Dorsal: grey only very faint. Ventral: stronger pure white glow.	Ventral: definite white glow. Tail tip: fur is relatively sparse and appears dull and yellowish, not fluorescing (in both 365 and 395–410 nm light). It is the white skin of the tail tip that is fluorescing.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Common ringtail possum (<i>Pseudocheirus peregrinus</i>) ♂ Whole animal to QM.	QPWS. Frozen.	Tail and ventrum white. Cheek greenish white. Greenish white flecked through dorsal fur.	Tail and ventrum white. Cheek greenish white. Greenish white flecked through dorsal fur.
Brushtail possums (Family: Phalangeridae)			
Common brushtail possum (<i>Trichosurus vulpecula</i>) ♂	JCU. Frozen.	At 310 nm: mild silvery blue-grey fluorescence over all body fur. Particularly white/bright on top of back feet. At 365 nm: same silvery blue-grey but much brighter. Tinge of pink on hindquarters: back leg and base of tail.	Silvery grey present, but less. Dark pink much more prominent. Most fur is fluorescent dark pink underneath with silvery-grey tips. Pink over all fur, including dorsal surface and through tail. Flank, hindquarters and base of tail: pink absent from base of strands, then more along shaft and brightest at tip. Back of neck: pink is at base of strands, getting less towards distal end of strands.
Common brushtail possum (<i>Trichosurus vulpecula</i>) ?	Roadkill. Flattened, dorsal exposed to >1 day sun and shade.	At 310 nm: none. At 365 nm: Dorsal: pink for proximal 2/3 of fur strands; brown tips absorbing. Ventral: dull orangey pink. Bright white adjacent to tail.	Dorsal: Same as at 365 nm, but a bit stronger orange. Ventral: Strong orangey pink. White not as bright.
Common brushtail possum (<i>Trichosurus vulpecula</i>) ♀ Virginal. HL=104.6 mm.	Roadkill. Fresh, left flank exposed to 8.5 hrs overcast.	At 310 nm: Dorsal, flank and ventral: pale brown fur turns blueish white; rest absorbing. At 365 nm: stronger sky-blue fluorescence on paler fur; rest absorbing. Some mild dusky pink.	Dorsal: mild dusky and dark pink patches flecked throughout. Flank: quite strong dusky pink in basal half of fur; rest absorbing. In side most protected from the sun. Ventral: mostly absorbing, but a wash of pale pink in small patches.
Coppery brushtail possum (<i>Trichosurus johnstonii</i>) ♀ PY preserved separately. HL=92.7 mm. Head to QM.	JCU. Frozen-thawed.	Not really fluorescent.	Pinkish orange colour over all fur, enhancing regular russet colour. Subtle, not bright. Not on tail.
Coppery brushtail possum (<i>Trichosurus johnstonii</i>) ♂	Roadkill. Fresh, dorsal exposed to 7 hrs sun.	At 310 nm: Dorsal and rump: none. Chest patch: some whole white mildly fluorescent strands peppered through. Ventral: turned mostly white with faint hint of dusky pink. At 365 nm: Dorsal: a little white-grey in parts. Chest patch: ~1/4 of fur fluoresces white in whole strands; rest absorbs. Ventral: mostly glows white quite distinctly, with small areas of dusky pink.	Dorsal: the ginger fur turns brighter light ginger. Yellow tips peppered through darker absorbing fur. Chest patch: the strands that fluoresced white at 310–365 nm are now pale yellow. Some strong pink through the ginger fur in patches of whole strands. Ventral: Mostly glows pale yellow, with a patch of pink.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Coppery brushtail possum (<i>Trichosurus johnstonii</i>) ♀ Virginal. HL=80.0 mm. Head to QM.	Roadkill. Fresh, night.	At 310 nm: Dorsal and flank: pale purply blue-grey on face, skin and basal half of underfur. Ventral: light greyish purplish blue, especially on face and arms. At 365 nm: same, but slightly less coloured.	Dorsal: light pink visible in basal half of fur where before it was blue. Rump fur pink throughout, and one patch particularly strong orange-pink. Flank: Basal half of strands really quite orangey pink; distal half remains pale ginger. Skin still white. Ventral: Orangey pink. Blue-grey gone.
Placentals			
Rabbits (Order: Lagomorpha. Family: Leporidae)			
European rabbit (<i>Oryctolagus cuniculus</i>) [naturalised] ?	Roadkill. Fresh, dawn.	At 310 nm: Dorsal and flank: none. Ventral: mild white in pale buff parts of fur. Tail: none. At 365 nm: Dorsal and flank: none. Ventral: stronger white with rest absorbing. Tail: white on paler parts of fur.	Dorsal and flank: Mostly absorbing, but turns pink in some otherwise light tan sections of fur. Ventral: mostly absorbing, but pale pink in pale buff tips and strands of fur. White milder. Tail: paler sections white. Some small patches of pale pink in whole strands of pale buff fur.
European rabbit (<i>Oryctolagus cuniculus</i>) ♂ [naturalised]	Roadkill. Fresh, dawn.	At 310 nm: not so much. At 365 nm: Dorsal and flank: not really. Ventral: whitish. Underside of tail and adjacent fur: bright white. Head: skin on inside of ears white.	Not as bright as at 365 nm.
European rabbit (<i>Oryctolagus cuniculus</i>) [naturalised] ?	Roadkill. Fresh, night.	Inside ear skin and eye light blue. Tried to scrape the fluorophores off the ear skin, but could not – the fluorescence was embedded in the skin.	Ventral and especially under tail fur white, but mild. Eye yellow. Ears white, not as bright.
Rats and mice (Order: Rodentia. Family: Muridae)			
Black-footed tree-rat (<i>Mesembriomys gouldii</i>) ? Whole animal to QM.	QPWS. Frozen.	Not much in general.	Pinkish wash over head and shoulders, orange over nape of neck.
Prehensile-tailed rat (<i>Pogonomys mollipelesus</i>) ♀ HL=35.4 mm. Whole animal to QM.	JCU. Frozen.	Not really fluorescent.	Dorsal: pink over fur. Not bright, but changes fur from russet brown to dusky pink. Ventral: white.
Giant white-tailed rat (<i>Uromys caudimaculatus</i>) ♀ HL=74.0 mm.	JCU. Frozen-thawed.	Dorsal: blue-grey in underfur/on skin. Ventral: light orange.	Dorsal and neck: orange flecked through. Orange is in the distal tips of fur, not the underfur. The fur with mild orange fluorescence is also pale orange in white light. Pink on face.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Giant white-tailed rat (<i>Uromys caudimaculatus</i>) ?	Roadkill. Fresh, left/ventral exposed to 9 hrs shade/sun.	At 310 nm: mild blueish white. At 365 nm: mild white, but mostly absorbing, except for white-fluorescing chest patch protected from the sun.	Dorsal: mild pink brindling in areas protected from the sun. Flank: mild pink brindling in areas protected from the sun, and some pale pink in underfur. Very slight yellowish through brindled dorsal and flank fur. Mild pale pink and yellow through brown fur. Ventral: some soft and pale pink in areas protected from the sun.
Pale field rat (<i>Rattus tunneyi</i>) ♀ HL=39.0 mm.	Roadkill. Fresh, dawn.	At 310 nm: not much – mostly absorbs. At 365 nm: Dorsal: pale blue fluorescent underfur with brindled brown tips. Ventral: tips fluoresce pale/white. Underfur absorbs.	Dorsal: similarly fluorescent pale blue brindled with brown. Ventral: similarly fluorescent blue-white.
Bush rat (<i>Rattus fuscipes</i>) ♀ HL=49.1 mm.	JCU. Frozen-thawed.	At 310 nm: some white-blue-grey fluorescence prominent throughout flank and ventral fur. At 365 nm: distinct blue-white fluorescence through fur, more pure where there is less melanin.	Same as at 365 nm, except fluorescence more grey-white than blue-white. Brightest in distal tips of fur.
Black rat (<i>Rattus rattus</i>) [naturalised] ?	JCU. Suburban (poisoned?). Fresh, 10 hrs in overcast rain.	Glowed bright blueish white on arrival, but had lost fluorescence when checked after several months of being frozen.	Same as at 365 nm.
Black rat (<i>Rattus rattus</i>) [naturalised] ♂ HL=48.1 mm.	Suburban. (poisoned?). Fresh, right flank in 9 hrs sun.	At 310 nm: blueish white. At 365 nm: very bright blueish white. Brighter on tips – darker blue-grey underneath, and paler tending to white at tips.	Bright pale greenish blue.
Delicate mouse (<i>Pseudomys delicatulus</i>) ♀ HL=34.0 mm.	JCU. Frozen-thawed.	At 310 nm: slight blueish grey-white. At 365 nm: bright blueish white over all fur, but brindled where more melanin.	Fluorescence more white than coloured, and does not glow as much as at 365 nm. More on ventrum than uniform over whole mouse.
Bats (Order: Chiroptera)			
Flying foxes and fruit bats (Family: Pteropodidae)			
Eastern tube-nosed fruit bat (<i>Nyctimene robinsoni</i>) ♂ FA=66.6 mm.	JCU. Frozen-thawed.	At 310 nm: yellow skin spots, and all yellow parts of skin, including nose and ear, fluoresce yellow. Fur a little grey. At 365 nm: yellow skin spots fluoresce bright yellow. Other skin, inside wings and muzzle, around eye, along bones and on genitals, also fluoresces yellow.	Yellow wing markings same as at 365 nm, bright neon. Fur mild blueish grey.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Eastern tube-nosed fruit bat (<i>Nyctimene robinsoni</i>) ♂	Tolga Bat Hospital. Frozen-thawed.	At 310 nm: blue fluorescence of fur and yellow fluorescence of wing markings, but less than at 365 nm. At 365 nm: reasonably bright light-blue fur over head and ventrum. All yellow skin markings, including wings, nose and ears fluoresce strikingly bright yellow. Some otherwise brown skin areas also fluoresce bright yellow: the face and inside the wings, both on the wing membranes and along the bones. Penis fluoresces bright yellow.	Same as at 365 nm, but less bright of both blue fur and yellow skin.
Eastern tube-nosed fruit bat (<i>Nyctimene robinsoni</i>) ♂	Tolga Bat Hospital. Frozen.	Same as specimen above.	Same as specimen above.
Eastern tube-nosed fruit bat (<i>Nyctimene robinsoni</i>) ♀	Tolga Bat Hospital. Frozen-thawed.	Same as Tolga specimens above, but ventral wing surfaces not as yellow as the males.	Same as Tolga specimens above, but ventral wing surfaces not as yellow as the males.
Eastern tube-nosed fruit bat (<i>Nyctimene robinsoni</i>) ♀	Tolga Bat Hospital. Frozen.	Same as specimen above.	Same as specimen above.
Eastern tube-nosed fruit bat (<i>Nyctimene robinsoni</i>) ♀	Tolga Bat Hospital. Frozen.	At 310 nm: expected colours present, but mild. At 365 nm: Fur: Dorsal: mostly absorbing. Ventral: greyish blue mid-ventrally, rest just absorbing brown. Head: blueish, but mostly just greyish brown. Skin: bright neon yellow wing spots and ear markings. Muzzle yellow but not as bright. Inside of wings and skin along bones yellow. Bone junctions pale blue. Eyes pale blue but not bright.	Fur: as at 365 nm but more reflectance. Skin: brighter yellow.
Eastern tube-nosed fruit bat (<i>Nyctimene robinsoni</i>) ? FA=65.8 mm.	Suburban. Decomposing, ventral exposed to ~weeks sun.	Fur mild blueish grey.	Wing spots and muzzle yellow, but much less bright than other specimens.
Eastern tube-nosed fruit bat (<i>Nyctimene robinsoni</i>) ♀ FA=68.6 mm.	Suburban. Fresh. Dorsal exposed to 6 hrs sun.	At 310 nm: head more purplish white than at 365 nm. At 365 nm: Fur: entirety of head purplish greyish blue. Dorsal absorbing. Ventral absorbing, and very mild grey-white fluorescence. Skin: yellow wing and ear spots, and eye rims, mild yellow, but mostly absorbing.	Less, but fur around neck, on ventrum and inside of wings fluoresces mid-yellow.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Eastern tube-nosed fruit bat (<i>Nyctimene robinsoni</i>) ♂ FA=66.8 mm.	Suburban. Left/ventral exposed to 1.5 days sun.	At 310 nm: all fur light purple to greyish purple, more so on ventrum. At 365 nm: Fur: light purple throughout. Skin: yellow wing spots yellow, but not bright. Inside wings faint mid-to-dark yellow. Some yellow on front of face. Wing bones pale blue.	Fur not so fluorescent; absorbing. Inside wings mid-to-dark yellow.
Spectacled flying-fox (<i>Pteropus conspicillatus</i>) ♀ FA=155 mm.	JCU. Frozen-thawed.	At 310 nm: only eyes and teeth. At 365 nm: blue-grey fluorescence through ginger collar. Some blue-grey flecked through main fur. Eye rings a little.	Dorsal: same as at 365 nm, but fluorescence more greenish grey. Ginger fur gives yellowish fluorescence. Ventral: grey-blue fluorescent strands throughout fur. Eyes fluoresce light blue.
Spectacled flying-fox (<i>Pteropus conspicillatus</i>) ♀ FA=160+ mm.	JCU. Frozen-thawed.	Same as specimen above, but less fluorescent on ventral fur.	Same as specimen above, but less fluorescent on ventral fur.
Little red flying-fox (<i>Pteropus scapulatus</i>) ♀ FA=124.4 mm.	JCU. Frozen-thawed.	At 310 nm: slight grey over head and neck. At 365 nm: grey fluorescence over head, not neck (absorbing). Eyes pale blue.	Brighter greenish grey fluorescence over head. Slight yellowy greeny grey along strip between ventral body and wings.
Microbats (Family: Vespertilionidae)			
Gould's wattled bat (<i>Chalinolobus gouldii</i>) ♀ FA=48.2 mm.	JCU. Frozen-thawed.	No fluorescence of fur.	No fluorescence of fur.
Hoary wattled bat (<i>Chalinolobus nigrogriseus</i>) ♂	Tolga Bat Hospital. Frozen.	No fluorescence of fur.	Fur completely absorbs and reflects.
Diadem leaf-nosed bat (<i>Hipposideros diadema</i>) ♀ Subadult.	Tolga Bat Hospital. Frozen.	Dorsal: none, just absorbing. Ventral: little whitish at edge of mouth, but generally none. Nose and inside ear white on skin. Bone junctions pale blue, but not rest of bones.	Dorsal: absorbing and reflecting. Ventral: slight pale green in tips unless fur lying flat. Chest yellowish green. Underarms white, slightly more than absorbing. Head: cheeks, face, noseleaf and ear fur mild yellowish green. Wing bones very mild pale blue, junctions white.
Ghost bat (<i>Macroderma gigas</i>) ♂ FA=100.0 mm. Whole animal to QM.	Kings Plains Station. Frozen. Exposed on barbed wire fence to ~5 hrs shade and dappled sun.	At 310 nm: none. At 365 nm: Dorsal: none except for base of ears. Ventral: light grey. Head: light grey around base of ears. Line of white skin that runs vertically in ears mild white. Wing bones light blue.	Dorsal: mild pale green. Ventral: good mid-level light yellow. Some fur inside both elbows slight pale pink. Head: light yellow on fur around edges of ears. Light, slightly greenish yellow on facial fur, same as ventral. Wing bones light yellow. No yellow on skin.
Large bent-winged bat (<i>Miniopterus orianae</i>) ♂	Tolga Bat Hospital. Frozen.	None in fur. Ventral wing bones bright pale blue.	Dorsal and ventral: very mild greenish yellow over fur tips.

Species, sex and size	Source and light exposure	Fur fluorescence at 310–365 nm excitation wavelength	Fur fluorescence at 380–410 nm excitation wavelength
Large bent-winged bat (<i>Miniopterus orianae</i>) ♀	Tolga Bat Hospital. Frozen.	Pale grey in lower ventral fur below genital area. Ventral wing bones bright pale blue. Claws light blue.	Dorsal: none. Ventral: mild pale grey, most prominent on lower abdomen.
Eastern long-eared bat (<i>Nyctophilus bifax</i>) ♀	Tolga Bat Hospital. Frozen.	Dorsal: none. Ventral: pale blueish grey, particularly around genital area. Head: pale blueish grey on muzzle and chin. Thin band of pale grey around base of ears.	Dorsal: none. Ventral: brighter and a bit more greenish than at 310–365 nm. Head: at base of ears. Also fuzz inside ears greenish and on forearms greenish blueish grey. Subtle.
Eastern long-eared bat (<i>Nyctophilus bifax</i>) ♀	Tolga Bat Hospital. Frozen.	Same as specimen above.	Same as specimen above.
Eastern long-eared bat (<i>Nyctophilus bifax</i>) ♂	Tolga Bat Hospital. Frozen.	Same as specimen above.	Same as specimen above.
Ride's free-tailed bat (<i>Ozimops ridei</i>) ♀	Tolga Bat Hospital. Frozen.	Some very mild light blue of throat fur.	No fluorescence.
Ride's free-tailed bat (<i>Ozimops ridei</i>) ♂ Subadult.	Tolga Bat Hospital. Frozen.	Maybe pale grey to chest and slight fluorescence of the rest of ventral fur. Almost imperceptible, very slight pale colour change. Slight blueish grey to bone junctions, and white teeth.	None on fur. Blueish to bone junctions.
Northern free-tailed bat (<i>Ozimops lumsdenae</i>) ♀	Tolga Bat Hospital. Frozen.	Subtle whitish to chest, and mild greyish white to ventral fur tips. Wing bones pale grey at junctions.	Dorsal: none; reflecting. Ventral: pale pink around neck, turning to pale orange on chest, then only flecked down through ventral fur. Wing bones pale grey, blueish at junctions.
Eastern horseshoe bat (<i>Rhinolophus megaphyllus</i>) ♀	Tolga Bat Hospital. Frozen.	Fur faint blueish grey on tips. Ventral wing bones light blue.	Fluorescence stronger but still mild. Greenish yellow on ventrum and band around back of neck.
Eastern horseshoe bat (<i>Rhinolophus megaphyllus</i>) ♂	Tolga Bat Hospital. Frozen.	Dorsal: mild grey around back of neck and below, especially edges. Ventral: greenish yellowish grey throughout fur tips. Inside ear skin white.	Dorsal: greenish yellowish grey as at 365 nm, but brighter. Ventral: quite mid-bright greenish yellow in tips all over, and extending onto patagium fuzz. Head: greenish yellow on cheeks and some on top of head.
Forest bat (<i>Vespadelus</i> sp.) ♀ FA=37.2 mm. Whole animal to QM.	JCU. Frozen-thawed.	Dorsal: a little grey-white tips to the fur. Ventral: bluey grey-white fluorescence on fur tips, particularly under chin.	Dorsal: slight yellow-grey on fur tips. Subtle. Ventral: yellow-grey on fur tips and under chin, but milder than at 365 nm. Subtle.
Dingo (Order: Carnivora. Family: Canidae)			
Dingo (<i>Canis familiaris dingo</i>) [naturalised] ♂ Pup.	JCU. Frozen-thawed.	Mostly absorbing. Mild white fluorescence of the white neck/chest fur. Paw pads and claws fluorescent.	Absorbing. Paw pads and claws fluorescent.

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Author Profile

Linda Reinhold graduated from The University of Queensland with Honours in zoology (taxonomy of bent-winged bats) in 1997. Since then, she has worked for state environment departments in Queensland and Western Australia, with stints in the Caribbean. Her interests have included bats, critical weight range mammals, herpetofauna and sea turtles. After stumbling upon photoluminescent mammals while out looking for glowing fungi in the forests around Cairns at night, she attended James Cook University to complete an MPhil on photoluminescence in fur.

The Dunstan Deals: How Some Geological Treasures Left Australia

Alan Rix¹

Abstract

During his tenure as Chief Government Geologist of Queensland from 1908 until 1931, Benjamin Dunstan sold a complete Triassic amphibian fossil and Queensland's largest meteorite to overseas institutions. When he died in 1933, he left a personal collection of fossils and other geological material which his widow Ada Dunstan sold to the Natural History Museum in London. These included a large number of meteorites from Queensland's famous Tenham meteorite shower. This paper documents these transactions and finds that there was little consideration given in any of these cases to the value of these important geological specimens to Australian public collections or to the nation's geological heritage. Ethical questions remain about the standards of provenance and ownership applied by both vendors and purchasers, in particular the role of Dunstan in his capacity as Queensland's senior government geologist.

Keywords: Edgeworth David, labyrinthodont, temnospondyl, Gladstone meteorite, geoheritage, Geological Survey of Queensland, *Paracyclotusaurus*, Tenham

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Introduction

The late 19th and early 20th centuries saw the emerging role of Australian-based scientists in the collection and description of Australia's natural heritage. Previously, the colony had relied on the expertise of specialists in the scientific centres of Britain and Europe to document this continent's fauna, flora and geology. This reliance reduced as scientific institutions (museums and universities) were established and developed in Australia (Basalla, 1967; MacLeod, 1980; Minard, 2018; Moyal, 1976; Vallance, 1978). The importance of the British Museum in collection and analysis did not disappear, however, and certainly in the geological sciences there remained close links with experts in London (and indeed Europe) who could bring their global knowledge to bear on interpreting Australian specimens (Turner & Long, 2016; Kohlstedt, 1980).

This residual use of British expertise in special fields remained a feature of Australian palaeontology at that time (Vallance, 1978; Brown, 1946). In other areas of the earth sciences, the geological survey organisations in the separate Australian states were focused on mineral exploration and discovery, given their relevance to economic prosperity (Johns, 1976). Likewise, discovery of and interest in meteorites was burgeoning and fed a flourishing international trade in meteoritic material (McCall et al., 2006).

These trends framed the tenure of Benjamin Dunstan as Queensland's Chief Government Geologist from 1908 to 1931. He led the exploration of Queensland geology and mineral resources in the first quarter of the 20th century, undertaking pioneering mapping (e.g. the Gympie goldfields), aerial surveying and palaeontological discovery (Sanker, 1981).

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When Dunstan died in 1933, his estate included a large collection of fossils and meteorites, which were sold to the British Museum of Natural History by his widow, Ada Dunstan. The collection included 102 stones from the meteorite shower that fell at Tenham Station in south-western Queensland in 1879. This group of Tenham meteorites was the largest from an observed Australian fall and remains a unique part of Australia's geological heritage.

Dunstan had earlier sold a temnospondyl amphibian fossil from Sydney, New South Wales (NSW), to the British Museum in 1927, which was significant in understanding the evolution and history of the group in Australia, and was the most complete specimen known at that time. Another Dunstan sale was of the Gladstone meteorite – to this day the largest ever found and documented from Queensland – to an American commercial organisation.

This paper traces the history of these three transactions and the implications for Australia's geological collections, curatorial practice and the nation's geological heritage. How do we interpret these sales in the context of the times? Can they be justified, even one hundred years ago? In the broad history of the export of Australian geological material in the 19th and 20th centuries, are these matters significant, and how should we assess today the actions of the Dunstans and the overseas institutions involved?

Dunstan's Temnospondyl ("Labyrinthodont")

The fossil temnospondyl which Benjamin Dunstan sold to the British Museum in 1927 is a classic case of opportunities gladly taken by the parties involved and geological collections in Australia ultimately forgotten. The fossil was an amphibian from the Triassic period, collected by Dunstan at the brick pits at St Peter's in Sydney (now Sydney Park). It was described by Professor D. M. S. Watson in 1958 as *Paracyclotosaurus davidi* and remains in the Natural History Museum, London (NHM). It is a famous fossil and was lauded by Watson at the time as "the most complete skeleton of a Triassic Labyrinthodont known ... the sole fossil from the Trias of Australia that could be dated with any accuracy" (Geological Society of London, 1927, p. vii). It is currently described by the NHM on their website as follows:

Our type specimen of *Paracyclotosaurus* is the only example of a complete articulated skeleton of a capitosaur, one of the major groups of Triassic temnospondyl amphibians.

Fossils found in the Triassic rocks and sediments around the Sydney region were widely reported in the newspapers in the 1890s and early 1900s. The concept of the ancient Sydney Basin being inhabited by large, predatory amphibians undoubtedly attracted readers: "... this beast was at least ten to fourteen feet in length, while in girth it was as large as an ox" ("Physalia", 1904; Anon., 1901; Hart et al., 2022).

It is not certain when Dunstan first found the fossil of the "labyrinthodont" (as these amphibians were then called), which was encased in a hard ironstone nodule within the shales of the brick pits. Dunstan himself did not reveal his find and, unlike ample coverage by newspapers of similar finds around Sydney (Anon., 1887a,b), his discovery seems to have received no reportage. Labyrinthodont footprints had already been found by others at the St Peter's pits, in addition to numerous fossil fish collected there by Dunstan. These fish were later described by Arthur Smith Woodward from the British Museum, along with details of the brick pit collection sites (Woodward, 1908; Turner & Long, 2016). Other labyrinthodont remains were found at Cockatoo Island in Sydney Harbour (Stephens, 1886), from Triassic sandstones near Gosford north of Sydney, and oil shales to the west, while additional labyrinthodont fossils were even found by Dunstan himself (along with fish, plants and shells) at Gibraltar Tunnel near Bowral, south of Sydney (Etheridge, 1888; Curran, 1899; Woodward, 1909). Yet, despite all these finds and the accompanying press attention over 20 years, why was the most complete fossil labyrinthodont from these Triassic strata never made public at the time?

Watson, in his 1958 paper (published 25 years after Dunstan had died), indicates that the nodule containing the labyrinthodont was found by "Mr B. Dunstan of the Geological Survey of N.S.W. [incorrect] around 1910". This date has become generally accepted but is also incorrect, and the timing of the find is important in understanding its fate.

Benjamin Dunstan had arrived in Sydney in 1882 from Victoria (where he was born in 1864),

and was employed at a firm of mining engineers, graduating from and later joining the staff at the Sydney Technical College, teaching geology. From there he moved to the Queensland Geological Survey (GSQ) in 1897 as an Assistant Geologist (Sanker, 1981). During his 15 years in Sydney, Dunstan actively collected fossils, published on some of his finds (Etheridge, 1888; Dunstan, 1893), donated specimens to the Mining Museum (Etheridge, 1894), had a fossil shell which he had found named after him (Etheridge, 1888), and in 1895 became a fellow of the Geological Society of London ("FGS"). A newspaper report in 1887 referred to a communication from the NSW Geological Surveyor, Mr Charles Wilkinson, to the Under-Secretary for Mines in NSW about "... Mr. B. Dunstan, the energetic geological student ..."

(Anon., 1887b). Despite being acknowledged in Sydney as a fossil collector, Dunstan apparently did not publicise or report his find of the complete labyrinthodont from St Peter's. There is no mention of it in the newspapers, nor in the NSW Department of Mines annual reports from 1887 to 1903 (by which time Dunstan was in Queensland). If he had collected it "around 1910" as Watson states, Dunstan was by then head of the Queensland Geological Survey, and his search for and collection of such an important fossil in another state would surely have been noticed.

If he had found the fossil when he was a student or technical college staff member in Sydney, he may well have been able to retain it without any fanfare. A clue from Dunstan reinforces the conclusion that the fossil was found well before 1910: in correspondence with R. J. Tillyard in March 1914 as Tillyard was commencing his analysis of insect fossils from St Peter's and had asked which pit they had come from, Dunstan wrote (Dunstan, 1913–1923):

About the St. Peter's locality I am a little bit in doubt, so many years have elapsed since they were found. I remember, however, that some came from Vickery's old pit, also the pit at the bottom of the road turning to the left just after passing over the St. Peters railway bridge from Newtown where I found the large labyrinthodon [sic].

In his resulting joint 1916 publication with Tillyard on the Mesozoic and Tertiary insects of Queensland and New South Wales, Dunstan described his find as follows (Tillyard & Dunstan, 1916, p. 9):

The [insect] specimens from the St. Peter's clay pits near Sydney were found many years ago by the writer while collecting fish fossils at the Carrington Brick Company's clay pit ... A large labyrinthodont about twelve feet long, almost perfect and wonderfully preserved, was also found.

A more precise date then appeared in a newspaper report in 1925 citing Professor Sir T. W. Edgeworth David of the University of Sydney (see below) as referring to the discovery "some 33 years ago" (Anon., 1925). This would make it 1892, during Dunstan's period in Sydney.

The question then becomes – if Dunstan did not publicise his find in 1892, why not? Presumably he wished to retain it for his own collection, rather than having to give it over to a public one. And where did he keep the fossil for over 30 years? The fossil itself was large, heavy and cumbersome to move (Watson, 1958, p. 236):

The nodule ... some 9 feet (2.75 metres) long, is split roughly into dorsal and ventral halves, each composed of more than fifty blocks, some of which weigh nearly a hundredweight [51 kg]. The matrix is an extremely hard and brittle ironstone, quite impossible to work.

It is likely, therefore, that the fossil travelled to Brisbane with Dunstan in the late 1890s (thereby bringing it across the colonial border when Queensland was a separate colony from New South Wales), and it was therefore outside NSW when first mentioned or shown to other scientists. A. S. Woodward of the British Museum, who had described the fossil fish from St Peter's and who also worked on tetrapods, was aware of and interested in the labyrinthodont, as he enquired of Dunstan in May 1911: "Have you made any progress with the development and study of the remarkable Labyrinthodont from New South Wales, about which we had some correspondence a few years ago? I shall be much interested to hear of the specimen" (GSQ Archives, 1911/000001). Dunstan replied rather casually

almost three years later, indicating that “I hope to see you when the Science Congress meets in Australia this year and we might make some arrangements about the large Labyrinthodont in my possession about which we had some previous correspondence” [GSQ Archives, 1914/000002).

Watson (1958) indicates that he first saw the fossil in July 1914. This was when he visited Australia from June 1914, as part of the large contingent for the British Association for the Advancement of Science’s 84th meeting held in several Australian cities in July and August 1914 (which Woodward in the end did not attend) (Anon., 1914a,b,c).

When Watson saw the amphibian, he would have realised its importance. He was soon to publish a major review of the evolution of the Amphibia (Watson, 1920), establishing a new order, Labyrinthodontia (for “all the large Amphibia”), and a new stereospondylous family, *Capitosauridae*, in which he included *Cyclotosaurus* from the Upper Triassic. He pinpointed Brisbane as the location of one of the Upper Triassic stereospondyls which he had been able to study, and thanked Mr Dunstan who “most kindly showed me his skeleton of *Cyclotosaurus*”. The specimen was also sighted in Brisbane in July 1923 by Professor E. C. Case of the University of Michigan (Anon., 1923).

Clearly Dunstan, having long held this significant fossil, was concerned as to how to deal with it, as he did not have the expertise to describe it himself. He advised Tillyard in September 1922 that “the labyrinthodont in my possession I have handed over to the Australian Research Council to have described. They are now writing to the British Museum about the matter” (Dunstan, 1913–1923). Thus began a process, facilitated by Professor Sir Edgeworth David, to arrange for the labyrinthodont to be worked on by Watson (the obvious person to do so) and ultimately to be sold to the British Museum.

The Australian National Research Council (which became the Australian Academy of Science in 1954) was established in 1919 (Elkin, 1954). Dunstan himself was chosen as a Queensland member of the ANRC in July 1921 and attended its first general meeting in August 1921 (Anon., 1921). It was at this meeting that Dunstan formally sought the assistance of the Council with his fossil (Branagan, 2005), and his entrusting the liaison

process to Edgeworth David (who was President of the ANRC in 1921–1922) helped ensure a more ‘official’ communication channel with London.

David wrote to the Director of the British Museum, Sir Sydney Harmer, in April 1923. Harmer agreed to receive the specimen and arrange for its description, and David informed Dunstan (Edgeworth David, 1923–1934; Labyrinthodont skeleton, 1927). It took some time for packing and transport to be arranged, and it was in an interview in September 1925, when David was en route to England, that he revealed that the fossil was to be described by Dr Watson, and “the present intention is that when described this specimen will be returned to Australia” (Anon., 1925). The fossil reached the British Museum on 5 February 1926, “addressed to Prof. Watson” (Labyrinthodont skeleton, 1927).

The question of the purchase of the labyrinthodont was raised with the Museum by Watson in a letter to F. A. Bather, Keeper of Palaeontology, on 3 June 1927, urging him to buy the fossil and indicating that “David tells me that Dunstan wants £500 for this specimen & I know (with certainty) that the American Museum is prepared to give him that sum”. Bather contacted David, who cabled Dunstan to ask if he would accept £500, which he did in a cable to Bather on 16 June. A proposal went to the Museum Trustees, who quickly approved the purchase at the end of June (Labyrinthodont skeleton, 1927; Dunstan et al., 1914–1955). It would equate to over UK£20,000 today.

In addition to the sale of the labyrinthodont, Dunstan offered to the Museum as a donation some additional specimens from his personal collection: type counterparts of the well-known fossil fish from St Peter’s described by Woodward in 1908, additional specimens of these same fish, and some further fragments of the amphibian. These were a significant ‘bonus’ for the British Museum, and were gladly accepted, arriving in London in November 1927 (Dunstan et al., 1914–1955; Edgeworth David, 1923–1934).

The labyrinthodont was revealed to the Geological Society of London in January 1927 by Watson and eventually described by him decades later, in 1958. This was despite Bather’s exhortation in July 1927 to Watson that, if the Museum Trustees were to spend £500, they expected results – he

would like to report to them that a description would be ready by the end of that year (Labyrinthodont skeleton, 1927). That was not to be, as preparation of the fossil took many years of careful work to make casts of the specimen (see Figure 1), given the

hardness of the ironstone matrix and the brittleness of the fossil bones (“a technical triumph” according to Watson). It was named *Paracyclotosaurus davidi*, after Edgeworth David through whose efforts it reached the British Museum in the first place.



FIGURE 1. Photographs taken by Dunstan before 1914, showing how the blocks of stone fit together. ‘A’ shows the upper surface of the whole animal and ‘B’ the lower surface. (Reproduced in Watson (1958). In copyright, digitised with the permission of the rights holder, the Trustees of the Natural History Museum, London. Reproduced under a Creative Commons Attribution-NonCommercial ShareAlike 4.0 International (CC BY-NC-SA 4.0) license.)

The sale of this significant fossil to the British Museum was undoubtedly a by-product of the desire by Dunstan to have the amphibian described, which was not possible in Australia at that time, and the recognition by all those involved of the importance of the specimen. Yet Dunstan was quite happy to sell, and there were no conditions attached to the sale – he even added the important fish fossils as a gift and gave the Museum “full rights” over the labyrinthodont. While having the fossil described was partly the reason for the Natural History Museum purchasing it (in addition to its great rarity), there were no clear stipulations about its eventual home. While its return to Australia was initially indicated by Edgeworth David prior to its purchase (Anon., 1925), 30 years were to elapse before it was finally described and named, by which time Dunstan, David and Bather were long dead, and the suggestion of having it returned to Australia was forgotten.

The fossil therefore remained with its owner, the Natural History Museum in London, as it does to this day. There have been occasional calls in recent years from the Australian media and scientists to have it repatriated, including as part of a wider proposal to return significant fossils “to their country of origin to restore our scientific heritage” (Young, 2015a, p. 29; Young, 2015b).

The Gladstone Meteorite

The level of personal possession Dunstan exercised over geological rarities was evident also in his official role in dealing with meteorites. Historically, there have been few meteorites found and reported to the Queensland Geological Survey or the Queensland Museum. The largest of these, the Gladstone meteorite (“Gladstone No. 1”, 14.5 cwt or 736 kg), was sold by Benjamin Dunstan in the mid to late 1920s to Ward’s Natural Science Establishment in Rochester, New York. The main mass is now held in the Field Museum in Chicago (Buchwald, 1975, p. 594).

There are several accounts of the discovery of the Gladstone meteorite. Simmonds (1964), who visited the site and talked with relatives of the finder, reported it as having been found in 1912 or 1913 by a surveyor’s assistant, Mr Tim Lee, during the construction of the Tondoon Creek dam south of Gladstone (now the lake at Gladstone’s Tondoon Botanic Gardens).

A contemporary newspaper account in March 1915 (Anon., 1915a,b) reports Mr E. C. C. Lee as having discovered the meteorite “a few days ago about five miles from Gladstone”. He apparently broke off a portion with a sledgehammer, which was sent for assay to the town of Many Peaks (at that time a copper mining settlement to the south of Gladstone).

This dating (but not the circumstances) is reinforced by Dunstan himself in his “Remarks on the Gladstone Meteorite” (14 September 1915), where he stated (Dunstan, 1915):

This very coarse meteorite was found about four months ago by a man while out shooting kangaroos and came into my possession after visiting the spot, where it was to be seen embedded in the ground, and decided that it was a meteorite.

Whatever Mr Lee was doing when he found the meteorite, March 1915 is the most likely date. According to Simmonds (1964), the meteorite was taken to Gladstone and then Brisbane to be stored at the Geological Survey Bulk Store. It would have taken some effort, as it weighed over 700 kg. It appears to have remained there, although it was displayed by the GSQ at the Brisbane Agricultural Show in July 1926 and illustrated in the *Queensland Government Mining Journal* in that year (Anon., 1926). However, a photographer captured the meteorite having just been delivered to the Field Museum in 1927 (see Figure 2), and newspaper reports in February and May 1929 show the meteorite at the Field Museum being examined by the head curator of geology (Anon., 1929a,b).

The meteorite had in fact been sold by Dunstan to Ward’s Natural Science Establishment in New York, in 1925 according to Thomas Hodge-Smith (1939) in his catalogue of Australian meteorites. Pieces were cut by Wards for sale, and the mass was then on-sold to the Field Museum, the purchase recorded in 1928 (Field Museum of Natural History, 1929). The shipment from Brisbane must have occurred soon after its exhibition at the 1926 Brisbane agricultural show.

Ward’s Natural Science Establishment was, in the late 19th and early 20th centuries, one of the world’s largest commercial purveyors of natural science specimens, and conducted an active trade in meteorites, amongst many other mineral, fossil and fauna items (see Ward Project website).



FIGURE 2. View of the Gladstone iron meteorite outside the Field Museum's south-west terrace near the shipping dock, Chicago, 1927. (Field Museum Library, Premium Archive, via Getty Images under license to the author.)

Henry Ward himself visited Australia in 1881, spending several months in the country, including a time at Melbourne's International Exhibition, "in which the Establishment is represented by a series of collections". He gathered a large body of animal and mineral specimens for the Establishment's catalogues, including pieces of the Cranbourne Meteorite, in addition to bird skins, platypus, echidna and other marsupials including four thylacine (Ward's *Natural Science Bulletin*, 1881; Ward's *Natural Science Bulletin*, 1882).

Ward was extremely active in the meteorite trade, cutting for and dealing with collectors and government officials all over the world. He visited Australia again in 1896 during an 11-month world trip, acquiring the Ballinoo (WA), Mooranoppin (WA, later found to be part of the Youndegin fall) and Nocoleche (NSW) meteorites, as well as the Mungindi, secured from the NSW Geological

Survey for cutting (the main mass later returned to the Australian Museum). The Mt Stirling (WA, also Youndegin) meteorite was cut by Ward's and returned to Sydney. The Roebourne meteorite was bought by Ward in 1896, as the Western Australian Museum was unable to purchase it. Ward was in regular contact with the British Museum about selling slices, as he had "put my prices very cheap" (Ward, 1897). Ward's *Meteorite Catalogue* of 1897 advertised small pieces of the Cowra and Mungindi meteorites, and in 1899 it offered pieces of the Cranbourne, several Western Australian specimens and the Queensland Thunda meteorite.

There is a wealth of scientific information available on the Gladstone No. 1 meteorite (Buchwald, 1975; Simmonds, 1964). As outlined above, it is an iron meteorite (classification IAB-MG) discovered in 1915, with a second Gladstone piece (24 kg) found in 1940 and later given to the GSQ. The main

mass of the Gladstone No. 2 meteorite is now in the collection of the Queensland Museum, which took over the GSQ holdings in 1993.

Another meteorite said to have been discovered possibly in 1880 or 1894 is the “Queensland Meteorite” (Dunstan, 1913). Research published in 1965 argues that, judging by its nickel content and structure, it possibly “represents a third piece of the Gladstone meteorite but found at an earlier date than the other two” (Wiik & Mason, 1965). Vagn Buchwald (1975, p. 593) in his definitive work on the iron meteorites, affirms this conclusion, which was originally suggested by H. C. Richards, Professor of Geology at The University of Queensland (Richards, 1930). Buchwald indicates that part of this meteorite was already held by Ward about 1894, but it did not appear in the Establishment’s meteorite sales catalogues between 1897 and 1907. A 72 g piece was held in the Ward-Coonley Collection of Meteorites in 1901, a special collection maintained by Ward based on his travels and the interest of the different pieces – “the authenticity of the specimens has been carefully studied” (Ward, 1901). The current whereabouts of this small specimen are unknown, although the Field Museum in Chicago acquired the Ward-Coonley Collection in 1912 (Heck & Holstein, 2021). A separate 94 g piece is held in the American Museum of Natural History (AMNH) in New York (Reeds, 1937).

Ward cut pieces of the Gladstone meteorite and was quick to trade them. The Australian Museum in Sydney received a 13.1 kg slice from Ward’s on exchange (Australian Museum, 1932). The American Museum of Natural History also received its 16 kg slice on exchange in 1930 (American Museum of Natural History, 1931), while the British Museum purchased its 7.4 kg etched slice from Ward’s in the same year (NHMUK Data Portal e373537; Dr N. Almeida, pers. comm. 16 July 2022). The Queensland Museum acquired its 42.4 g slice in February 1940 from the Australian Museum on exchange (Queensland Museum, 1911–1969, p. 45).

Regretfully for Queensland’s geological heritage, however, once the Gladstone meteorite, by far the largest single meteoritic stone yet found in Queensland, was available and assayed, Dunstan was quick in trying to sell it. By September 1915

he had written to the Smithsonian Institution in Washington DC to offer them the Gladstone meteorite “which is in my possession for disposal” (Dunstan, 1915). Dunstan also tried unsuccessfully in 1917 to sell it to the AMNH for \$5,000 (Hovey, 1882–1925).

Dunstan’s letter to the Smithsonian is addressed from the Geological Survey Office, so it could be assumed that the proposed transaction was an official one, although a curious feature of the letter is the emphasis Dunstan places on “my possession” and himself (not the GSQ organisation) as the vendor. Also unusual is that a copy of the letter does not appear in the relevant volume of the GSQ Letter Books, the collection of official outgoing correspondence from the Survey (Geological Survey of Queensland, 1914–1915). The letter had an attachment “Remarks on the Gladstone Meteorite”, which set out a description and assay details and provided photos and a 2”, half-ounce slice. The assay itself was probably conducted officially on behalf of the Geological Survey of Queensland, although there is no extant documentary evidence of this.

Dunstan proposed to sell under “any convenient arrangement”, including cash for the whole specimen, or part cash and “part exchange in meteorite”, and “at fair market value”. He indicated if the offer was not satisfactory, he would cut up the meteorite and dispose of it in slabs through a Sydney mineral dealer (which he did not do).

Dunstan’s references throughout the letter to “I am willing to sell”, “I to retain ...”, “I am prepared to sell”, “my agent” suggest a strong personal investment in this process. It is not clear whether he was trying to sell the Gladstone meteorite on behalf of the Survey or on his own behalf, and the GSQ archives are incomplete. A personal observation from George W. Card, curator of the NSW Mining Museum, to G. T. Prior, the head of the Mineral Department at the British Museum in June 1927, is therefore of relevance (Card, 1927):

... my friend, B. Dunstan, Government Geologist there [in Brisbane], is a man of peculiar temperament. I believe he regards the meteorites as his own property ...

By the time of Card’s letter, however, the Gladstone meteorite was already on its way to the United States.

Unfortunately, there appears to be no evidence as to how much Ward's paid for the meteorite, whether it was sold by the GSQ or by Dunstan personally, and where the payment went. However, the outcome was the same: Richards (1930) refers disparagingly (and rightly) to this transaction as the Gladstone meteorite having been "disposed of" by Dunstan.

The Tenham Meteorite

Another Dunstan deal awaited Queensland's most important meteorite. The Tenham meteorite fell in Western Queensland in 1879, observed by the local landowners, the Messrs Hammond. Many stones were collected, and the finds (already mentioned in the press in 1909) became more widely known in 1913 when Mr R. A. Wearne, Principal of the Ipswich Technical College, was informed and 15 specimens were subsequently brought to Brisbane (Anon., 1909; Anon., 1913a,b).

The 102 Tenham stones which are now in London were sold to the British Museum in 1935 by Ada Dunstan, the widow of Benjamin Dunstan, as they were thought by her to be part of the personal collection of fossils and minerals included in her late husband's estate. In the course of the purchase of the stones, the British Museum (notably L. J. Spencer of the Mineralogical Department) did not enquire about their provenance, nor did Spencer raise the issue in his 1937 study of the Tenham meteorites.

Spencer (1937) indicates that the meteorites "... came along quite casually as an appendix to a collection of fossils" – they were, in fact, the last items on a list of boxes of (mainly fossil) specimens provided by Ada Dunstan when she approached the Museum in June 1934 about possible purchase of her late husband's collection. Dunstan's earlier sale of his amphibian fossil to the Museum was the impetus for Ada Dunstan to contact the Museum about possible purchase.

In subsequent correspondence with both Dr Spencer in the Mineralogical Department and Dr W. D. Lang, Keeper of the Geological Department, it was agreed that the Museum would purchase the fossils for UK£250 and the Tenham meteorites for UK£150 (Tenham meteorite shower, correspondence and papers, c. 1904–1935; Dunstan et al., 1914–1955). The fossil collection

included additional counterparts (including type counterparts) of the Triassic fish fossils collected by Dunstan at St Peter's, others of which he had donated to the Museum when they bought the amphibian in 1927. Over 1000 Upper Triassic insect fossils from Queensland (including types and type-counterparts) were likewise part of the deal (Rix, 2021).

After the sale was concluded in May 1935, Ada Dunstan forwarded to Dr Spencer notes on the meteorite prepared by Dunstan, and what she claimed were "four additional pieces of the Tenham meteorite". Spencer expressed the view that "I think it quite time something was published but as yet I have not been able to collect much information", "... It will all be pieced together in time" (Natural History Museum, 1935–1937).

Spencer did publish (1937) a detailed analysis of the Tenham meteorite shower and the meteorites themselves, assisted by the limited documents from Dunstan's papers sent by Ada Dunstan. A further investigation was undertaken by the GSQ in 1962 (Brooks et al., 1964). Other meteorites (the so-called "Warbreccan stones") already in the possession of the British Museum were identified as part of the Tenham meteorite shower. They had been bought by the British Museum in 1905 from a London contact of an Adelaide dealer on behalf of the person who originally acquired them from the Tenham owners (Prior, 1916; Spencer, 1937; Tenham meteorite shower, correspondence and papers, c. 1904–1935).

In 1938 a separate group of 124 Tenham meteorites (numbered 1–127, with three missing) was displayed at the Geological Survey Museum in Brisbane (Queensland Department of Mines, 1939). These were then purchased from Orea Hammond (daughter of the original discoverer, Michael Hammond) by the Queensland Government, and were deposited at the Queensland Museum in June 1939, where they remain (Queensland Museum, 1911–1969, p. 43). Heber Longman, the then Director, lauded them as "the largest collection of meteorites from one shower possessed by any museum in the world" (Anon., 1939), and additional analysis, acquisition and exchanges have occurred to this Tenham material since that time.

The question remains, however: how did Dunstan come by his large collection of Tenham

meteorites? As described in Spencer's analysis, each stone at the British Museum is numbered T1, T2, etc., in white paint. This is consistent with Dunstan's pedantic curatorial practice, as seen in his collection of fossil insect specimens kept in small boxes numbered in white paint in the same style (Rix, 2021). Dunstan apparently regarded these Tenham stones as his to curate and care for, although the presence of four un-numbered stones sent later to London by Ada Dunstan is anomalous, if they are indeed part of the Tenham shower.

Dunstan's Retirement, Death and Estate

Dunstan retained the Tenham meteorites after he had left the Geological Survey. He departed government service in controversial circumstances – indeed, his response to the announcement of his retirement by the then Minister for Mines on Christmas Eve 1930 was: "It was the first I have heard of it" (Anon., 1930a,b,c). It came at the end of what Denmead called an "ultimate decline into a dispirited indifference" (Denmead, 1956), a gradual waning in Dunstan's Survey interests and "his growing absorption in his own affairs".

This was clearly recognised in the upper echelons of the Department of Mines, for Dunstan was in effect forcibly retired ("got rid of" according to the Member for Bowen, Mr Charles Collins, in late 1931) (Queensland Parliamentary Debates, 17 November 1931). The Department considered that Dunstan was not properly discharging his duties and recommended that he be retired as of 31 January 1931, with just one month's notice (Queensland Department of Mines, 1930). Dunstan set up as a consulting geologist after his retirement, worked on goldfield geology in New Guinea and North Queensland, and on his death in 1933 was working for the Australian Mining Trust Syndicate (Anon., 1933a,b,c).

Denmead (1956) assessed Dunstan as:

a man of small stature and light build. He possessed a good measure of personal charm, particularly towards the opposite sex. He was an expert mineralogist and had a passion for gemstones, of which he was a connoisseur. He was an artist of no mean order, specializing in water colour, and was a keen musician. He was also a talented public lecturer.

A curious aspect of the sale of Dunstan's collections by his widow relates to his last will and testament, dated 31 August 1933, two days before he died of gall bladder cancer at a private hospital in Toowong, Brisbane. He left the proceeds of his life insurance policy (£400) to Sarah Alcyone May Thorpe ("spinster" of Bulimba, Brisbane), who was also named as an executrix alongside his wife, Ada. Probate was granted but revoked by the Court in April 1936 after it was revealed that the two witnesses to the will (a "nurse" and a "housewife") did not sign in Dunstan's presence. The will became invalid and Dunstan was declared intestate. His wife was appointed administrator, thus removing Sarah Thorpe from any benefit, the whole of his estate going to his wife and children. The value of the estate was also increased by the value of his gems, meteorites and fossils (£575), the sales to the British Museum having been finalised (Dunstan, 1933; Supreme Court of Queensland, 1936). The proceeds from Dunstan's geological collection were therefore significant in the final probate value, and Ada Dunstan had argued strongly to the British Museum to reconsider the value of the fossils, which led to an increased offer (Dunstan et al., 1914–1955).

The Provenance of the Dunstan Tenham Meteorites

The first group of Tenham meteorites to be revealed and exhibited were those brought by Mr Hammond to R. A. Wearne in Brisbane in 1913 (see Figure 3). These 15 were recorded in GSQ's *Queensland Mineral Index and Guide* in the same year (Dunstan 1913, p. 718). Hodge-Smith's 1939 catalogue of Australian meteorites refers to 102 stones at the British Museum, one at the Australian Museum and 127 at the Queensland Geological Survey Museum lent my Miss O. A. Hammond. This last group comprised the collection bought by the Queensland Government in 1939 and now held at the Queensland Museum (see above).

So where did the 102 "Dunstan" stones come from? Fifteen of them are the original stones publicised in Mr Hammond's Brisbane visit in 1913, which Dunstan was said to have intended to examine, assay and study further. The largest, weighed at 5241.9 g by Dunstan in 1913, was numbered "T1" and is the largest of those now in

London, officially 5245 g. Spencer (1937) records that Ada Dunstan sent to him from her husband's papers "a map, photographs, certificate of chemical analysis, and various scrappy notes" (none of which are now available, as there is no consolidated collection of Spencer's post-retirement papers). He indicates that a Dunstan MS note from 27 June 1913 lists those 15 stones, their weights and specific gravity. The analyses were conducted for Dunstan by the Government Chemical Laboratory in Brisbane, and photographs taken by the Department of Agriculture and Stock.

Spencer concludes that Dunstan's 1913 sketch map of the Tenham fall was traced from a pastoral map, rather than based on a visit. Whether or not Dunstan did visit the remote south-western

Queensland location at a later date is not known, although in the mid-1920s the Geological Survey undertook work in west and north-west Queensland, Dunstan himself reporting in detail on this (Dunstan, 1920). The 1926 Department of Mines annual report further identified the south-western corner of the state (adjoining South Australia and New South Wales, where Tenham Station was located) as deserving of geological study, to assist in better understanding the Great Artesian Basin. Dunstan was already engaged in this work, having produced a map of Queensland's Artesian Basin for the Third Interstate Conference on Artesian Water in 1921 (Queensland Department of Mines, 1922). He also highlighted the opal fields in the same area. There is, however, no evidence that he visited Tenham.



FIGURE 3. The original Tenham meteorites revealed in 1913. Mr M. Hammond (owner of Tenham) left and Mr R. A. Wearne (geologist) right. (Wiley Studios Brisbane photo, reproduced from *The Queenslander*, 2 August 1913, p. 26.)

It is therefore likely that Hammond brought or sent more meteorites to Brisbane at Dunstan's request. Hammond was reported as a regular visitor to the city (Anon., 1915c), and from later donations and purchases it is clear that there were some hundreds of stones gathered by the Hammond family. A letter from Dunstan to Hammond (Dunstan, 1916) indicates what probably occurred:

Several times I have attempted to get a trip arranged to enable my making the inspection, at your kind invitation, of the place where these meteorites fell, and the matter has again been brought forward for consideration. I spoke to Mr Hamilton, our Minister, but he is most anxious for me to go north on some coal work, and very reluctantly I must admit that at least within the next three months no opportunity will be presented to make the visit. The Royal Society has been urging me to give them the details of the find of the stones, but this I will not do unless I can do the thing thoroughly, and to do this it would be necessary to have the complete collection of the "Tenham Meteorites".

Could you send those you have in hand down to me for this purpose, and save the visit until some time later. I am also interested in another single specimen which fell near Bedourie about the middle of June 1915. A piece of this I have now and it is very fresh looking but otherwise much like those of yours. Through getting in touch with you and the subsequent publication of the articles about the meteorites I have had several inquiries, and the specimen [came?] to light near Gladstone and this I am now having described. So you see we will have quite an exhibition of meteorites ...

I also want to get out your way on quite a different matter, i.e. Artesian Water, as this subject is of keen interest to me just now ...

The "Bedourie meteorite" mentioned was sent to Dunstan in 1916, but its authenticity was not confirmed by him (and it is therefore not recognised officially), although Dunstan described it as "very much like a stony meteorite, and resembles others which have been found out west" (Dunstan, 1916). What is certain, however, is that the Tenham meteorites were received by Dunstan as Government Geologist in 1913 in order to "thoroughly examine

and have assays made of the specimens in his possession, and publish a full description of them later" (Anon., 1913a). This he never did, and retained the original 15 Tenham stones and another large group after he left government service. Had he lived longer he may have written about the meteorite, as he had promised to do many years before, but the "scrappy notes" which Spencer received from Ada Dunstan apparently did not constitute the results of a thorough study, and suggest that the possession of the stones was more important than their description. There is no Dunstan archive, so we do not know if he did more work on the stones or if more information was held by him.

These meteorites represented part of the fall of Australia's largest observed meteorite shower, were an important mineralogical asset of Queensland and had not been studied. Dunstan had shown himself capable of meteoritic analysis, had professional assays available to him, but produced nothing in the 20 years the Tenham stones were in his keeping. Just as H. C. Richards in 1930 (see above) had criticised Dunstan for "disposing of" the Gladstone meteorite, he also referred in the same paragraph to the "undescribed collection of 102 fragments" of the Tenham meteorite, which he would have known were in Dunstan's possession, as he and Dunstan were closely associated on geological matters in Queensland (Richards, 1930).

So the large collection of Tenham meteorites held by Dunstan went to London. Fortunately, many of the remaining Tenham stones did find their way in the late 1930s to the Queensland Geological Survey and thence to the Queensland Museum, and are used today as an active collection for research, exhibition and education.

Discussion

It is difficult after one hundred years, and in the face of incomplete evidence, to definitively assign motives or to make judgements about the Dunstons' sales of geological material. The now-recognised concept of geoheritage was still in the future; nonetheless, public museums of natural history were well established, collections were being built up and displayed, and societies for the study and appreciation of the natural world were active. Indeed, Dunstan himself was a member of The Royal Society of Queensland, the Royal Geographical

Society of Queensland and the Geological Society of London.

What were Dunstan's responsibilities as Chief Government Geologist? His primary purpose was to oversee the surveying and documenting of the State's mineral resources. He had no official responsibility to protect and retain geological heritage, although part of his duties included GSQ's geological museum and its role in featuring the rich geological resources of the state (Queensland Department of Mines, 1930; Anon., 1905). Other state geological surveys had the same mission: to document their geology and mineral resources. Their collections at that time were primarily for reference purposes (Johns, 1976).

The labyrinthodont was a fossil which Dunstan himself had collected before joining the GSQ. He obviously regarded it as a personal possession, rather than as a rare specimen that should be housed in an Australian museum or state collection. The meteorites, however, were quite different: they were matters over which he unquestionably had formal responsibility and authority in Queensland. In his official capacity he inspected the Gladstone meteorite *in situ* and took charge of it on behalf of the GSQ, and likewise borrowed Mr Hammond's Tenham meteorites for analysis. Unfortunately, Dunstan seems not to have regarded his duties or his professional responsibilities as extending to preservation of these geological treasures for Australia.

Dunstan's maintaining a personal collection of fossils and other material was of itself unexceptional. However, retaining fossils (e.g. the Ipswich Triassic insects), especially types and type-counterparts, which he had collected while working for the Geological Survey, or meteorites given into his care as the head of the GSQ in the expectation that he would study and report on them, would not pass the ethical standards test today, and arguably not even then. Yet, under the Queensland Public Service Acts of 1896 and 1922, while an officer could not be negligent, careless, indolent, inefficient or incompetent in the performance of their duties, standards of ethical conduct were not otherwise laid down, in contrast to civil service practices today which emphasise the management of conflicts of interest under clear codes of conduct (Bridgman, 2019).

In 1926, Mr Card from the Australian Museum

did express his concern (see above) as to Dunstan crossing the boundary between the professional and private in his attitude to meteorites. Kohlstedt (1980, p. 11) documents that "throughout the last half of the nineteenth century (indeed to the present day) the ethics governing the private collections and activity of museum employees were unclear and a cause of serious controversy". Clearly, the dilemma posed by Dunstan's passion for collecting was not new.

In relation to the sale overseas of Australian specimens in Dunstan's time, the Commonwealth's *Customs Act 1901* regulated exports, but there were no restrictions on the export of "fossils and other geological material". These were first included in the *Customs (Prohibited Exports) Regulations* in 1953 under its Second Schedule requiring Ministerial consent, and legislation covering moveable cultural heritage (including "natural science objects" such as meteorites) was not passed until 1986.

In the 1920s and 1930s, therefore, there was no legal prohibition on the sale and export of geological material, and neither custom nor practice inhibited the deals that were done. The interesting remark about the labyrinthodont attributed to Edgeworth David, however, that "this specimen will be returned to Australia" (Anon., 1925), suggests recognition on his part at least of the fossil's inherent value to its country of origin. Even Dunstan had in 1918 acclaimed the "very rare and valuable" fossil collection at the GSQ: "... the collections are important accessories to a geological survey ... some of the fossils are priceless and the work of caring for them should be assigned to an officer specially trained" (Queensland Department of Mines, 1919, p. 196). As one of Australia's senior government geologists, Dunstan might perhaps have been expected to acknowledge the value of the Sydney labyrinthodont in the same way.

Dunstan's need to see the amphibian fossil which he had collected at the age of 28 and stored for over 30 years scientifically described was obviously important to him, but the offer to gain financially was also attractive. He was aware of the fossil's significance and value, and both Edgeworth David and the British Museum knew of his interest in selling. Edgeworth David was the intermediary for the whole process, but the end result of that successful negotiation was a financial benefit to

Dunstan, the eventual description of the amphibian, but the loss to Australia of a remarkable fossil.

It was not, however, necessary for the Gladstone meteorite to be “disposed of” (as H. C. Richards had described it). Admittedly the international trade in meteorites was lively, and many Australian specimens, including those from Queensland, had made their way to dealers and institutions overseas well before the specimen from Gladstone was found. But Dunstan had the meteorite thoroughly analysed and knew what it represented. He could easily have acted as the distributor of specimen slices to relevant museums but chose to try immediately to sell it, albeit unsuccessfully until 10 years later. He claimed to have “partly prepared” a paper for The Royal Society of Queensland, but no such paper ever appeared. It would seem that Dunstan’s primary objective was financial gain, either for the Geological Survey or himself. Card’s observation that Dunstan “regards the meteorites as his own property” seems entirely apposite.

It was possibly that attitude which led Dunstan to retain in his own private collection the Tenham stones which, in the absence of evidence to the contrary, were the property of the Hammond family. While Dunstan may have intended to prepare a study of these but was not able to do so before he died, it appears that he never got close to achieving the objective he had expressed to Mr Hammond in 1916 in arguing the case to get more stones. While Dunstan may have continued to consider the meteorites as a “loan”, it was his holding onto them (presumably in the end at his home) for 20 years until his death that enabled his widow to sell them. Ada Dunstan herself clearly needed the funds, caught up as she was in legal and monetary complications arising from her late husband’s having provided for another woman in his will. At the same time, the British Museum gave no consideration to the provenance of these meteorites and was pleased to accept them without enquiry as to their origin and rightful ownership.

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Walter Hill: The Scotsman Who Grew Queensland

David Nielsen¹ and Anoma Kumarasuriyar¹

Abstract

For 26 years, Walter Hill was the longest serving and industrious Director of Brisbane's Botanic Garden. During this period, he created a world-class botanic garden and public park in an area that subsequently became known as Gardens Point. Hill trialled, acclimatised and introduced numerous plants that made significant contributions to Queensland's agricultural and economic prosperity. Hill also began the cataloguing of Queensland's native flora and assisted in the exploration and settlement of the state. This article details Hill's background before his 1852 arrival in Australia, and his 1855 employment, first as Superintendent and then later as Director of the Brisbane Botanic Garden. Also explained is his role as Colonial Botanist, his involvement with the Queensland Acclimatisation Society, and his efforts in cultivating numerous exotic plants, such as *Victoria regia*. Finally, to crystallise his achievements, this work details Hill's participation in an 1862 voyage to Queensland's Cape York. Although Hill's scientific accomplishments are relatively meagre when compared to his contemporaries, such as Ferdinand von Mueller at the Melbourne Botanic Garden, and Richard Schomburgk at the Adelaide Botanic Garden, Hill's substantial horticultural contributions to Queensland are nevertheless important and largely unacknowledged by the historical record. This work therefore calls for further research to fully document his substantial impact and fascinating career.

Keywords: Brisbane Botanic Garden, *Victoria regia*, Queensland Acclimatisation Society

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Introduction

In the context of European settlement of Brisbane, the area that today comprises the eastern half of Gardens Point was from 1826 of crucial importance because it was the location of the Government Garden that grew food for the fledgling settlement. In 1854, the Government Garden evolved into the Brisbane Botanic Garden (BBG), which transformed into the City Botanic Gardens in the later decades of the 20th century. Today, the western half of Gardens Point has developed into the principal campus of the Queensland University of Technology and is the location of the Queensland Parliament. Regardless of these more recent additions,

Gardens Point continues to hold an enduring connection to the rapid development and expansion of the BBG under the direction of Walter Hill. Under his leadership, the derelict Government Garden was expanded and totally transformed within a few short years into a world-class Botanic Garden and public park. During this formative period from 1855 to 1865, Hill's achievements were numerous and significant. He is acclaimed as the first to comprehend the commercial potential of the macadamia, planting the BBG's first tree in 1858 (Nock et al., 2019, p. 2). In the 1860s, numerous specimens of botanical interest, such as abundant palms and pines, tamarind and mahogany trees,

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had been cultivated by Hill. In 1862, Hill, together with John Buhot, crystallised Queensland's first domestically produced sugar from cane grown in the BBG (Hill, 1862a, p. 3). This event is important as it signalled the foundation of Queensland's sugar industry, which today adds 3.8 billion dollars to the state's economy (Lawrence Consulting, 2022, p. 8).

Hill's primary activities of experimentation and acclimatisation were centred on establishing the economic potential of flora that was mostly exotic but also native to Australia. While these activities were perfectly aligned with the primary purpose of a Botanic Garden, the development of the BBG into a public horticultural showcase was likewise at the forefront of Hill's mind (Dowe, 2016, p. 489). During this formative period, the industrious and hard-working Hill also made significant contributions to the physical exploration of the state, the cataloguing of its native flora, and the dissemination and advancement of botanical knowledge. While the scale of his achievements and the scope of his work in Queensland are too numerous and varied to detail in this article, what follows is an overview of his significant achievements, mostly in the early 1860s.

Walter Hill and His Early Years in Australia

Walter Hill was born on 31 December 1820 in the Scottish village of Scotsdyke, County Dumfriesshire (Anonymous, 1904, p. 25; Maiden, 1909, p. 377). Before the age of 16, Hill had started a gardening apprenticeship at Balloch Castle, County Dunbartonshire, under the direction of his brother David who was the head gardener. Following this, Hill found employment at the F. Dickson Nursery on Inverleith Row in Edinburgh, where he worked under James Kelly who was a "propagator in the houses" (Anonymous, 1904, p. 25). Hill moved to Minto House in County Roxburghshire as a foreman and worked under Daniel Crichton who was the head gardener and forester. After spending two years at Minto House, Hill accepted a position at the Royal Botanic Garden, Edinburgh, under curator William McNab (Anonymous, 1904, p. 25) in 1841 (Maiden, 1909, p. 377). Following McNab's recommendation in 1843, Hill was appointed as foreman of the Propagation and New Plant Departments at the Royal Botanic Garden, Kew (Anonymous, 1904, p. 25; Maiden, 1909, p. 377).



FIGURE 1. Walter Hill. Image courtesy of John Oxley Library, State Library of Queensland.

While at Kew, Hill was "certified" by both Director William Hooker and Curator John Smith as having been suitable for the position of curator at the Cambridge Botanic Garden, indicating that he was apparently well regarded by both of his superiors (Anonymous, 1904, p. 25); however, this appointment did not eventuate (Anonymous, 1904, p. 25). While employed at Kew, he married Jane Smith on 16 September 1849 in Middlesex, England (Queensland Family History Society, 2003). Reportedly, as he was "ambitious of rising in his profession" and to increase his botanical understanding, Hill left Kew in October 1851 and migrated to Australia on the ship *Maitland* (Anonymous, 1904, p. 25).

Arriving in Sydney in February 1852, Hill held a notable letter of introduction from William Hooker addressed to amateur botanist William Sharp Macleay (Sim, 2006, p. 22). Hill also presented additional letters of introduction to Governor Fitzroy and the Colonial Secretary, Edward Deas Thomson. After a short stay in Sydney, Hill proceeded to the Turon River goldfields where he prospected without success for six months. He travelled to the Beechworth and Bendigo goldfields before returning to

Sydney in the middle of 1854, where he was introduced to the plant and animal collector Frederick Strange through Macleay (Anonymous, 1904, p. 25).

Following an invitation by Strange, Hill joined a voyage to Keppel Bay and Cape York in 1854 onboard the ketch *Vision* (Anonymous, 1904, p. 25). Strange funded this through a commercial agreement with Joseph Rossiter and Gordon Korff to collect “tortoise shell, oil or any other produce, and to trade and barter” from the islands of the north-east. Strange bought, or leased, the *Vision* in Sydney for this voyage and sailed to Moreton Bay on 4 September 1854 (Whittell, 1951, pp. 111–114). Hill boarded the vessel in Moreton Bay, sailed north on 29 September and reached the “second Percy Island” on 14 October (Anonymous, 1854, p. 2). A violent encounter with the local inhabitants resulted in the death of four members of the party, including Strange. Although Hill was on the island at the time, he avoided this event. The *Vision* returned to Moreton Bay on 13 November (Anonymous, 1854, p. 2), with Hill proceeding to visit relatives in Bathurst (Anonymous, 1904, p. 25).

Hill and the Brisbane Botanic Garden

Established in February 1853, the Moreton Bay Horticultural Society (MBHS) (Anonymous, 1853, p. 2) advocated for a “Public Garden” in Brisbane to cultivate and acclimatise plants (Anonymous, 1855, p. 2). The MBHS lobbied Charles Fitzroy, the Governor of New South Wales, in December 1853 for the establishment of a botanic garden, where indigenous plants could be collected, studied and classified, while also acclimatising exotic tropical plants. Following Fitzroy’s visit to Brisbane in March 1854, he granted seven acres for the establishment of the Botanic Garden in the area of the previous grounds of the old Government Garden. For the role of first superintendent, William Macleay recommended Hill as both available and as a very practical botanist and horticulturalist (Anonymous, 1904, p. 25). Following an additional recommendation of Hill by the local Government Resident, John Wickham (Sim, 2006, p. 16), Hill was appointed on 21 February 1855 by the New South Wales Government (McKinnon, 2005). His appointment was officially

proclaimed in the *New South Wales Government Gazette* on 23 February 1855 (Government of New South Wales, 1855a, p. 483). To support Hill, a Committee of Management was appointed, which comprised William Augustine Duncan, Robert Ramsay Mackenzie and Thomas Jones (Government of New South Wales, 1855b, p. 1780). On the insistence of Hill (Anonymous, 1904, p. 26), Wickham in 1855 lobbied and successfully expanded the grounds of the Botanic Garden to 28 acres southward into Garden Point and eastward towards the Brisbane River (Sim, 2006, p. 16). Hill, while confirming these points in his report to the Colonial Secretary on 6 May 1861, did describe them slightly differently, stating that the initial grounds measured six acres and were subsequently enlarged to 27.5 acres. He stated that it was the Trustees, who it is assumed were the Committee of Management, who had secured the larger site allocation, with an extensive river frontage that was at that time enclosed by a fence (Hill, 1861, p. 1115).

In 1859, when Queensland achieved territorial separation from New South Wales, Hill was officially appointed as the Director of the BBG and Keeper of both the Government Domain and Brisbane’s Queen’s Park (Queensland Government, 1860, p. 104). In 1860, Hill was additionally appointed and tasked with the collection and transport of numerous articles of Queensland’s “produce or manufacture” for display at London’s 1862 Great Exhibition for Industrial Products (Queensland Government, 1860, p. 355). Hill was also appointed as Queensland’s Government Botanist during this period (Sim, 2006, p. 18). Adding further to his mounting involvements and responsibilities, in 1863 Hill was appointed as Queensland’s Selector of Agricultural Reserves (Queensland Government, 1864, p. 829). This rapid progression undoubtedly reflected the great faith that the Queensland Government had in Hill – a faith that was inspired by his physical transformation of, and the activities that he undertook within, the BBG.

As early as 1856, visitors to the BBG recounted how Superintendent Hill had shown them a plan of the garden (Anonymous, 1856, p. 2). They noted the long river frontage, numerous walkways, the labourers’ accommodation, and that only eight of the 27 acres had been “trenched and planted”.

As for the plan, they reported that it specified the arrangement of the garden into 34 divisions (Anonymous, 1856, p. 2):

1. Main entrance from Albert Street.
2. and 3. Entrance to the grand walk.
4. Pinetum. – The genera will be mixed, in order that the failure of defective growth of one genera may have a chance of being compensated by the growth of that or those adjoining.
5. Arrangement of plants that are indigenous to the four quarters of the globe.
6. Plants that are indigenous to Australasia, and used for their timber in industrial arts.
7. Florists' flowers, arranged according to their colours, and times of flowering.
8. *Araucaria Bidwillii* and the Bowrie Pine.
9. Ornamental Flowering Shrubs.
10. Rosarum (climbing roses).
11. Dwarf and Standards.
12. *Bambusa*, *Araundinacea*, and other weeping trees.
13. Aquarium, for the *Victoria Regia*, and other aquatics.
14. Rock work.
15. Aquarium, for the use of the nursery-ground etc., etc.
16. A general arrangement according to the natural method of Jussieu, etc., etc.
17. Illustrations on plants, as the different kind of live hedges. These must always be matter of interest to the agricultural population of this colony, but though of vast importance they have been neglected.
18. Arrangement of plants that are indigenous to New Holland, arranged according to the method of Linnaeus.
19. Rustic seat, moss house.
20. Plants cultivated for their timber.
21. Plants cultivated for their herbage and forage.
22. Plants cultivated for their seeds and straw.
23. Plants cultivated for their medicinal properties.
24. Plants cultivated for their utility in arts and manufactures.
25. Plants cultivated for their fruits as an article of the dessert.
26. Plants cultivated chiefly for their roots.
27. Plants cultivated for their aromatic substances.
28. Museum of Economic Botany, for the deposit of those vegetable products that are

eminently curious or in anywise serviceable to mankind; it is consequently of the highest importance, if simply for instructional purposes, and essential to a young commercial colony, as must be evident to any person who reflects on the innumerable wants of the human race. The ship-builder, the carpenter, the cabinet-maker, the general merchant, the manufacturer, the weaver, the physician, the druggist, the dyer, the oil and colourman, etc., etc., would find the several objects in which they are from, and the names of the plants from which they are procured.

29. Pleasure ground. The trees forming the arbo-retum will be planted at stated distances in a fixed order, along the walks of the pleasure ground. The clumps necessary for breaking the lines and fulfilling the general plan of the garden, will be made up of a selection of really ornamental trees, quite independent of the scientific collections.
30. Reserve ground as a nursery for plants.
31. Enclosure for dwelling houses and other offices.
32. Grass lawn for horticultural flower shows.
33. Bank near the river – grass.
34. Labyrinth.

While neither the location, or existence, of this original plan is known, the layout and features described on it have been proposed as similar to those that were shown on *Ham's Map of the City of Brisbane* of 1863 (Sim, 2006, pp. 24–26).

The prominent, central feature evident in the Botanic Garden on *Ham's Map of the City of Brisbane* is an "Aquarium for *Victoria regia*". Considering this emphasis, this was clearly important and thus requires further explanation.

The 1856 visitor's report contained a description of the "Aquarium for *Victoria regia* and other aquatics" (Anonymous, 1856, p. 2):

... beautiful little oblong island, which is approached by two rustic bridges, decorated with fanciful rock-work, among which are planted bananas to afford a temporary shade to numerous tender ferns, until palms and other trees supply the want. This lovely spot has been reclaimed from a marshy piece of ground, and the place is still surrounded with tall bamboos and their young shoots.



FIGURE 2. Ham's map of the city of Brisbane, Queensland. Image courtesy of John Oxley Library, State Library of Queensland.

However, the aquarium was generally known as Fern Island (Sim, 2006, pp. 24–27). Fern Island was in the middle of a low-lying portion of the Garden and was constructed on the site of an earlier pond created by Charles Fraser in 1828. It consisted of a long, elongated oval island that was planted with native and exotic plants, with palms, tree ferns and epiphytic ferns being dominant. A walkway on the island's outer periphery facilitated visitor views, and the entire island was surrounded by a moat that was spanned by two wooden bridges. While the name Fern Island was generally accepted, names such as Palm and Bamboo Island were also commonly used (Sim, 2006, p. 30).

Victoria regia, renamed *Victoria amazonica*, is a giant water lily native to South America. In the middle of the 19th century, it created a sensation in Britain and Europe because of its enormous leaves, massive fragrant flowers with curious pollination habits, and having been named after Queen Victoria. Tremendous prestige was garnered by those that cultivated and flowered *Victoria regia*,

especially in Britain and her colonies, where it was a powerful symbol of the British Monarch and the Empire that she represented.

On 26 January 1858, Hill wrote to *The Moreton Bay Courier* and reported that seeds of *Victoria regia* had been presented to Brisbane's Botanic Garden by the Curators of the Royal Botanic Garden, Kew (Hill, 1858, p. 4).

However, Hill had noted that a specimen of *Victoria regia* was already present in the BBG in 1857 (Hill, 1869, p. 581):

The chief feature in the way of substantial improvement, during the past year, has been the addition of two artificial lagoons, in a line with the original two. One of these I intend devoting to the cultivation of the famous *Victoria Regia* a water lily [*sic*] of surpassing beauty. A specimen of this I had in the Gardens as early as the year 1857, and managed to rear it into flower; for want of water supply, however, it finally perished.



FIGURE 3. Fern Island in the BBG in the 1870s. Image courtesy of John Oxley Library, State Library of Queensland.



FIGURE 4. Fern Island as painted by Marianne North in 1880. Image courtesy of Royal Botanic Garden, Kew (CC BY-NC licence).

In a report that Hill made to the Queensland Legislative Assembly on 5 July 1879, he clarified that the actual flowering had happened in January 1858 (Hill, 1879, p. 968):

In 1857, seeds of the *Victoria Regia* were received from the late Sir William Hooker, Royal Gardens, Kew, one of which germinated, and was reared in a tub; it was then placed in the aquarium surrounding the palms and tree ferns, at the end of October in the same year, and, in the last week of January following, I had the pleasure of seeing its first flower expand, which was eight inches in diameter, the leaves measuring three feet six inches. In consequence of heavy rains about that time the temperature of the water was lowered considerably, and the plant perished. From then

until now I have been unable to rear plants from the seeds sent me, but it gives me much satisfaction to say that seed of it has now germinated, and I hope to be able to plant it out in the middle aquarium about the end of October, when the water, in all probability, will be at a genial temperature to receive it.

If Hill did manage to flower *Victoria regia* in 1858, this would contradict the accepted facts concerning its history in Australia (the first flowering was recorded as having been accomplished in Melbourne by Ferdinand von Muller in 1867 (Anonymous, 1867a, p. 2; 1867b, p. 3; Maroske, 1992, pp. 4–5), while its second flowering in 1868 was accomplished by Richard Schomburgk in Adelaide (Anonymous, 1868, p. 169; Payne,

1992, pp. 193–200)). If indeed Hill was first, it would offer a perfect example as to why the Queensland Government would have had such faith in Hill and thus allowed his rapid promotion.

While Hill's accomplishments in creating a horticultural showcase complete with *Victoria regia* were impressive, it was his activities with economic and medicinal plants that held the most potential for Queensland. These undertakings were facilitated within the state-sponsored BBG and private concerns like the Queensland Acclimatisation Society.

Hill's Cultivation of Economic and Medicinal Plants in the Brisbane Botanic Garden

The scale of Hill's success in acclimatising productive trees and plants was detailed in his 1861 (p. 1115) report to the government: "... flourishing in full vigour" in the garden were allspice, clove, nutmeg, cinnamon, black pepper, coffee, tea, camphor, tamarind, bread fruit, ginger, arrowroot, caper, tobacco, rice, sarsaparilla, cocoa, date, guava, mango, apples, alligator pear, plum, litchi and papaw. Hill mentioned that he had planted 20 types of grapes, 12 types of pineapples, eight banana and 10 orange varieties, together with eight varieties of cotton. He further described his successes in cultivating sugarcane (*Saccharum officinarum*) and stated that its "thriving condition would seem to indicate that it might be cultivated with profit" (Hill, 1861, p. 1115). Many of these species subsequently became significant agricultural crops, with sugar being a prominent example.

Hill wrote to *The Courier* on 25 April 1862 and included a sample of sugar, produced by John Buhot, that was manufactured from immature sugarcane grown in the BBG. While this was the result of a crude test, which was solely intended to ascertain if sugar could be granulated, Hill stated that a further experiment was planned with proper equipment that would supposedly produce sugar of superior quality than that generally sold in Queensland (Hill, 1862a, p. 3). Buhot subsequently wrote to *The Courier* on 2 June 1862 and observed that while he was the first person to have crystallised sugar in Queensland, he was not the first to do so in Australia, this being achieved by Thomas Scott in New South Wales some months earlier. Nevertheless, he clarified that he had conducted two experiments with sugar crystallisation,

the first being done with "bright yellow sort – the Otaheitan" sugarcane from the BBG, while the second, "from Cleveland, were from the dark cane ribbon" and conducted under the direct supervision of L. Hope and the partial supervision of G. Raff and Hill (Buhot, 1862, p. 2). These events launched the Queensland sugar industry, and the BBG subsequently distributed numerous plants to aspirant sugarcane growers in the years that followed. For example, in 1870 Hill noted in his annual report that there were 36 varieties of sugarcane growing in the BBG and that he had distributed upward of 50,000 plants, mostly within Queensland (Queensland Government, 1870, pp. 308–309). Equally, in Hill's 1872 report, he documented that 539 individuals and businesses had received 50,200 sugarcane plants that comprised 14 varieties that were being grown in the BBG (Queensland Government, 1872, p. 1317). More remarkably, in Hill's 1876 report, he documented the distribution of 98,000 sugarcane plants and that he had 40 varieties growing in the BBG (Queensland Government, 1876, p. 980).

In 1862, Hill explained that his experiments in cultivating the tea plant (*Thea bohea*) had been very successful, with numerous plantations that comprised several hundred plants growing within the BBG. As with tea, Hill likewise mentioned that his trials with cotton were also doing well, as was *Coffee arabica* that was raised from seed obtained four years previously. He expressed his confidence that tea and coffee could therefore be successfully cultivated in Queensland. Hill remarked that a vacant area to the west of the Pinetum had been planted with 25 new species of pines. Fibre-yielding plants, including the "Manilla hemp, the Jute, the China grass, the African hemp, etc.", together with the medicinal *Cinchona calisaya*, the natural dye *Indigofera indica*, *Urania speciosa* (traveller's tree) and *Xanthochymus pictorius* (mangosteen) were also identified as being present in the garden (Hill, 1862c, p. 2). Hill noted that he was extremely optimistic that he could cultivate *Cinchona calisaya* with success. He also stated that he would arrange to procure *Cinchona succirubra*, this being "the most valuable of the species" (Hill, 1862c, p. 2). As for exchanges with other institutions, Hill thanked the directors of the Ceylon, Melbourne and Sydney Botanic Gardens, together with James Veitch of the Royal Exotic

Nursery in London, James Warner of Kangaroo Point and L. Hope of Kilcoy. Eight thousand plants and 700 packets of seeds were reported as having been distributed within Queensland, with 1600 tea, 2000 sugarcane, 200 coffee and 160 ginger being the most numerous species. Hill noted that the economic success of Queensland would be advanced because of the BBG's success in cultivating and distributing these, with sugarcane being identified as a prominent example (Hill, 1862c, p. 2).

In 1864, Hill noted that the successful experiments conducted during the previous two years had confirmed the viability of growing tea, coffee, sugar, cotton, cinnamon, allspice, ginger, indigo and tobacco in Queensland. Hill reported that numerous tropical species introduced into the garden in the previous five years, including *Mangifera indica* (mango), *Anona squamosa* (custard apple), *Diospyros kaki* (Chinese date plum) and *Tamarindus officinalis* (tamarind), had all borne fruit, while the jaca tree (*Artocarpus integrifolia*) was bearing fruit for the first time. As for sugarcane, a new plantation had been established to ascertain the cultivation viability of several species including the “Walta”, ‘Tiloo-ura’, ‘Tiboo’, ‘Chica-ga’, ‘Pinang’, ‘Diard’ and ‘Guinghan’ (Hill, 1864, p. 1038). Hill again reiterated his belief that sugarcane would prove tremendously successful in Queensland, while also emphasising that he had distributed a significant number of cuttings to growers and that their increasing demands had far exceeded his limited capacity to supply their needs. Hill wrote that *Cinchona calisaya*, noted in his 1862 report (p. 2), was in a “healthy condition” (Hill, 1864, p. 1038) and that he had approached both William Hooker at Kew and William Denison in Madras to procure seed of *Cinchona succirubra*. Hill's success with oranges, including the mandarin, Saint Michael's bahia, Siletta, blood and Parramatta, was noted, with those varieties being less susceptible to disease. Several new plants and species were introduced during the previous two years, including two new varieties of banana, *Jatropha Manihot* (casava) and *Jacaranda mimosifolia* (Hill, 1864, pp. 1037–1038).

In 1865, Hill reported that his plans to establish a *Cinchona* plantation on the site presently occupied by bananas had suffered a setback. This was because two Wardian cases from Walter Denison in Madras and a further one from Dr Thwaites

in Ceylon had been damaged, suffered shipping delays, and were thus dead when they eventually arrived in Brisbane. The plantations of tea, coffee, cinnamon, indigo, senna, pineapples, grapes, etc., all continued to flourish; *Jatropha Manihot*, being the sweet, or blue, cassava variety was also mentioned by Hill as having been successfully cultivated. He also reported that a large donation of cork trees (*Quercus suber*) had been received from Mr George Macleay and that he had distributed all of them to various individuals within Queensland (Hill, 1865a, pp. 1084–1085; 1865b, p. 4).

Hill and the Queensland Acclimatisation Society

While Botanic Gardens were state-sponsored initiatives that acclimatised foreign flora and established the potential of native flora, Acclimatisation Societies were essentially parallel private concerns, established for the public good, that acclimatised, exchanged and disseminated knowledge of native and exotic fauna and flora. In other words, the activities of the Acclimatisation Societies intersected with those of the zoological, philosophical and natural history societies, and those of the botanical gardens with agricultural and pastoral associations. Importantly, within the British Empire, Australia boasted more Acclimatisation Societies than any other colony (Tiffin, 2007, pp. 166–168).

In 1862, numerous advertisements appeared in *The Courier* that called for gentlemen to attend the founding meeting of the Queensland Acclimatisation Society on 14 August 1862, an event that would be chaired by Governor George Bowen (Anonymous, 1862d, p. 3). During this inaugural meeting, Hill, amongst others, was enrolled as both an ordinary member and appointed in an ex-officio capacity to the Society's first governing Council (Anonymous, 1862d, pp. 2–3). The Council met for the first time on 21 August 1862 and elected a Management Committee that consisted of John Bramston, Kearsey Cannan, Robert Douglas, Hill, H. C. Rawnsley, T. B. Stephens and William Thornton (Anonymous, 1862c, p. 2). Having thus been established, the Society's Secretary, Lewis Bernays wrote to the Editor of *The North Australian and Queensland General Advertiser* on 25 October 1862 and requested public assistance in the acquisition of “anything either in the animal or

vegetable kingdom which the Society may deem it desirable to endeavour to acclimatise in this colony". Specifically, the Society sought to acquire "deer from the Cape of Good Hope" and "Cashmere goats", while also requesting donations of local talegallas, kangaroos, emus and pigeons (Anonymous, 1862b, p. 3). To facilitate acclimatisation and exchange, on 25 November 1862 the Society resolved at its first quarterly members' meeting to lobby the government for two grants of land. The first site was to be in the immediate vicinity of Brisbane and would serve as a depot where animals and birds, either received or intended for exchange, could be kept or acclimatised. The second was to be located some distance from the city and would be much larger to accommodate deer that would supposedly be received from Southern Africa and India (Anonymous, 1862a, p. 2).

The government responded favourably to the Society's first request and granted 20 acres

of yet-to-be-demarcated land in York's Hollow (Anonymous, 1863b, p. 2). Once surveyed, this initial grant was expanded to 32 acres of undulating land on the north-western side of the Bowen Bridge and named Bowen Park after Governor George Bowen. Hill, together with three other members, was appointed to devise the layout of the Park, which would be used for the purposes of the Society and public recreation (Anonymous, 1864, p. 2).

Before the establishment of Bowen Park, Hill and the BBG's involvement with the Queensland Acclimatisation Society appears to have been mainly centred on accommodating the plants, birds and animals intended for either acclimatisation or exchange. For example, in the record of the Society's quarterly meeting held on 4 March 1863, it was noted that several "Chinese sheep" were in a paddock to the rear of Hill's cottage in the BBG.

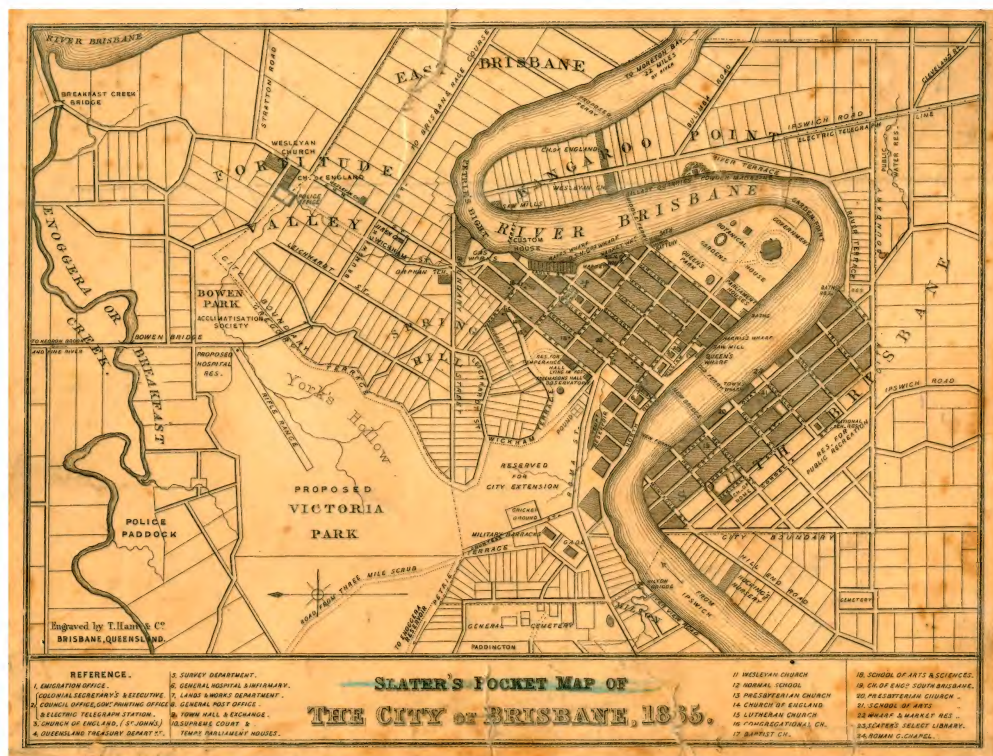


FIGURE 5. Slater's 1865 Pocket Map of Brisbane, showing Bowen Park and the BBG. Image courtesy of John Oxley Library, State Library of Queensland.

Observing that the current parliamentary stables would soon become unavailable to the Society, a suggestion was made that this paddock could also be used as a “new repository ... for contributions of birds and animals forwarded from the country” (Anonymous, 1863a, p. 2). Likewise on 4 May 1863, Hill reported to the Society’s Management Committee that he had received a “wild dog” that had been forwarded to the Society by Mr Macgregor of Rockhampton (Anonymous, 1863c, p. 2).

A keeper was soon required to care for the numerous birds and animals being kept on behalf of the Society within the BBG. As such, by the middle of 1863 a sum of £1 was approved by the Society’s Council to provide for this appointment. (Anonymous, 1863d, p. 2). On 24 August 1863, it was reported that the Society had constructed an aviary in the BBG because of the large number of birds being kept there. A further important motivation for the construction of this aviary was the need to display these birds and thus make the Society’s activities known to the general public (Anonymous, 1863c, p. 2). This aviary had been the topic of discussion and numerous prior meetings of the Society (Anonymous, 1863c, p. 2; 1863d, p. 2) and it was noted that while the aviary was initially located in the BBG, the Society’s intention was that it would be moved to Bowen Park at a later date (Anonymous, 1863d, p. 2).

The Cape York Expedition of 1862

An 1862 voyage to Far North Queensland was an event that perfectly encapsulated many of Hill’s diverse activities: his experiments with plants, establishing the agricultural potential of Queensland, exploration of the state, and the communication of botanical information to the botanical epicentre at Kew.

In 1860, Governor Bowen called for the establishment of a supply station near Cape York. A voyage was undertaken from August to October 1862 by HMS *Pioneer* to ascertain the best site for the station’s establishment (Bowen, 1863–1864, p. 114). Bowen noted Hill as the botanist who had accompanied this voyage (Bowen, 1863–1864, p. 116). Hill’s account of the voyage stated that the *Pioneer* departed Brisbane on 27 August and their first stop on 3 September was Fitzroy Island, followed by Pelican Island on 5 September and

Booby Island on 9 September. In addition to flora, Hill also recorded the geography, availability of fresh water sources, agricultural potential of the soil, and the fauna of all the places visited during the voyage. On 10 September, the *Pioneer* commenced its return voyage with a stop at Dayman’s Island. There, Hill collected two unknown plant specimens. The voyage then proceeded to Evans Bay, south-east of Cape York Island, where the palm *Sagus farenifera* was documented by Hill. Albany Island was visited on 15 September, with Hill noting the collection of a species of tree that he termed “*Parinarcum*”, together with *Dioscorea bulbifera* yams. From 18 to 20 September, the mainland was visited and two large streams and soils suitable for small-scale agriculture were noted. Hill likewise noted the presence of ginger and turmeric and his interaction with the local inhabitants, whom he described as helpful and peaceful. Hill recommended this location, Port Albany, to Bowen as the site for the proposed station. On 26 September the *Pioneer* reached the mouth of the Endeavour River, and two days later it arrived at Dunk Island in Rockingham Bay, where Hill again reported the presence of *Dioscorea bulbifera*. The Mackay River was explored on 29 September and Hill collected three interesting plants: “cycadea”, Zingiberaceae and *Musa jackeyi* banana. Hinchinbrook Island was explored on 30 September, followed by Port Denison Bay and the settlement of Bowen on 1 October. While in Bowen, Hill surveyed the Don River and collected 50 botanic species, none of which was new to science. On 10 October, Rockhampton’s Agricultural Reserve and Recreation Ground was visited, with Hill recording his intention to plan its “laying out and ornamentation ... with trees, shrubs, etc.” (Hill, 1862b, pp. 2–3). Gladstone’s Agricultural Reserve was examined on 18 October, followed by a visit to Maryborough’s Cotton Company on 21 October, where Hill noted very healthy cotton plants on the 20 acres under cultivation. The *Pioneer* returned to Brisbane on the morning of 24 October (Hill, 1862b, pp. 2–3).

In Hill’s 1864 annual report to the Government, he stated that during his trip on the *Pioneer* he had collected some examples of flora that he had dutifully forwarded to Kew, noting that he had encountered the sandalwood tree (*Santalum album*) on the banks of the Endeavour River and also at

Port Denison (Hill, 1864, pp. 1037–1038). A further reflection on the 1862 expedition was made in Hill's annual report of 1865. He observed that he had collected numerous useful indigenous plants that would be particularly attractive for exchange. These included a new edible plant, a pineapple-like "Scitamineous plant", a species of *Eugenia* that was known to settlers as the cherry tree, a novel "Cycadaceous plant", as well as *Cycas media*, *Musa jacksonii*, and *Nelumbium leichhardtii*, together with numerous ferns that Hill believed were new to science (Hill, 1865a, pp. 1084–1085; 1865b, p. 4).

Conclusion

We are fortunate that Hill's most enduring botanic contributions, like the original macadamia tree planted in 1858, are still physically evident within the grounds of the City Botanic Gardens. These bear testament to his efforts in acquiring, cultivating and acclimatising exotic and native flora. Within the BBG, Hill, as more of a practical gardener

than a trained botanist, experimented, refined and distributed agricultural and food crops which fed colonial Queensland and laid the foundations for future significant industries such as sugar. However, because the Gardens have long since transformed into a public park, Hill's ground-breaking contributions in the introduction of numerous crops and fruits into the Queensland colony are not evident today. Hill was likewise active in the cataloguing of Australia's native flora and in the European exploration of the colony, and played a formative role in establishing and moulding the fledgling Queensland Acclimatisation Society.

Walter Hill was thus central to the formative development of Queensland. Regardless of his impressive record, the fact remains that this research has only briefly documented some of his accomplishments until 1865. As such, Hill is still a largely unknown personality and further research is necessary to firmly establish his legacy in the historical record.

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Author Profiles

David Nielsen's current research reinterprets the formative histories of the architectural modern movement. The general themes of his work include Expressionism and the Deutsche Werkbund, and key personalities like Bruno Taut, Adolf Behne and Herman Muthesius. To accomplish this reinterpretation, he uses the perspectives offered by German industrialisation and exhibition architecture of the 18th and 19th centuries, while similarly including the diverse influences of Gothic architecture, the *Victoria regia* lily, Luxfer prisms, botanical glasshouses and Orientalism.

Anoma Kumarasuriyar has conducted extensive research on Brisbane's historic residential architecture and the adaptive reuse of exemplars like Newstead House and Old Government House. Her research investigates Asian architecture and culture, with a particular focus on Japan. She has published on cultural sustainability, including the rock-cut architecture of Iran's Kandovan village and refugee settlements in Jordan.

Book Review

BOOK REVIEW

Invention to Innovation: How Scientists Can Drive Our Economy

By Larry Marshall with Jenna Daroczy

CSIRO Publishing, 288 pp., Paperback

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In a country that has nurtured numerous inventions and great scientific minds that have shaped our modern world, *Invention to Innovation* makes the case that Australian science can deliver economic success requisite with its extraordinary potential. Drawing on his decades of experience in the world of Silicon Valley venture capital (VC) and most recently as Chief Executive Officer of CSIRO, lead author Dr Larry Marshall provides readers with a positive market vision for Australian science while identifying barriers to the immense commercial success seen in Silicon Valley and Europe. *Invention to Innovation* is an enjoyable read for venture capitalists, industry, government and aspiring scientist-entrepreneurs. It highlights how Australia's innovative spirit and enormous intellectual capital may foster world-class commercial success if these entities resolve to nurture the Australian innovation ecosystem with a new perspective.

The book presents numerous barriers that may prevent widespread commercial success stories in Australian science. The chief barriers seem to be cultural in nature, elements of a disposition pervasive throughout the Australian innovation environment that stifles the market for deep-tech opportunities. These barriers include the fear of failure among all stakeholders within the system (generally cautious corporate decision makers), discouraging scientist entrepreneurship, and a finite view of domestic market size. The reader cannot distil tangible remedies from the wealth of content because of the amorphous nature of the problems presented. However, the book convincingly illustrates these cultural barriers and their chilling effects on Australian innovation through a plethora

of anecdotes from Silicon Valley and quotes from leaders in technology commercialisation.

A broad theme that looms large throughout the book is a call for a richer VC environment in Australia. Whether that be encouraging greater risk tolerance for deep-tech investment or overcoming the cultural disposition to fear failure in professional investing, these insights are undoubtedly derived from the lead author's extensive experience in the world of VC. The advantages of Australia's emerging VC environment are described in some detail and compared to international counterparts. Upon reading Chapter 2 of this book, venture capitalists around the globe would find these advantages an appealing reason to consider Australian innovations over those in other markets. One concrete example provided is the low barrier to entry to a company listing on the Australian Securities Exchange for companies seeking an Initial Public Offering. This is reinforced by Australia's abundance and diversity of scientists from its world-class universities poised to deliver innovations that VC resources can promote.

In addition to broad themes, the book provides encouraging remarks and compelling advice for scientists aspiring to entrepreneurial outcomes for their research. The reader may leave later chapters confident that Australia indeed needs more scientist-CEOs. Throughout the book, the organisational benefits of this unique class of innovators are described, as well as mindset and market changes that could increase their prevalence among corporate executives. Readers will not find concrete proposals for these changes. Rather, Chapter 4 provides general proposals such as giving STEM students or recent graduates more exposure to business education, moving the mindset among the

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scientific community away from research perfection and more towards market readiness, and allowing government or private industry to reward scientists who can clearly promote singular commercial applications of impressive research. Chapter 5 can be read as a handbook of informed advice for scientists and individuals looking to improve the market vision for their research. The general proposals and advice presented in these chapters are laudable and may be helpful to readers in government, science, VC, and industry seeking to tap the entrepreneurial potential of Australia's world-class scientific corps.

As it relates to industry, the book calls readers in the corporate world to move away from a culture that stifles innovation. The authors attribute this corporate disposition to what they describe as a false understanding of potential domestic market size. Readers are encouraged to cultivate the innovation in their respective sectors to expand the size of their market rather than stamp out startups or technologies seeking commercialisation that are currently perceived as competitors. This appeal against the highly competitive instincts of Australian industry is another instance in which the authors seek a cultural shift, informed by a lived experience in the innovation environment of Silicon Valley that they consider to be more ideal.

No doubt as a result of Dr Marshall's time as CEO of CSIRO, the authors illustrate that institution as the protagonist that can propel Australian innovation forward. In the absence of distinct

recommendations, it is a compelling message for the reader that CSIRO-led endeavours, like the accelerator and venture funds, can be the foundation upon which a more meaningful government campaign to promote innovation can be built. In Chapter 8, the book calls for bold, high-minded innovation missions to be the driving mechanisms by which government can lift technologies and scientists that seek to make the largest impacts on the issues of our time. This may be seen as a vague yet flexibly ambitious model for government promotion of Australian innovation derived from international examples of success.

Invention to Innovation delivers a new vision of Australian innovation in the 21st century. It is a vision of Australian scientific excellence and leadership brought to the global marketplace for lasting domestic economic benefits and progress in the evolution of international technology. The book is structured in a manner that readers of all backgrounds would find approachable, and indeed the Australian VC, industry, government and science communities would benefit greatly from its words. Marshall's anecdotes from an extensive career and thoughtful quotes from other leaders add a richness to the narrative that compels conversation. After completing *Invention to Innovation*, the reader is likely to leave convinced of Australia's unique innovative spirit and intellectual abundance that may position Australian technologies to take a greater role on the global stage if the aspirations of this book come to fruition.

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Maroccia, J. (2023). Book Review. *Invention to Innovation: How Scientists Can Drive Our Economy*, CSIRO Publishing, 288pp, Paperback. *Proceedings of The Royal Society of Queensland*, 132, 75–76. <https://doi.org/10.53060/PRSQ23.r1>

Royal Society of Queensland Reports

PRESIDENTIAL ADDRESS 2023

Climate Action Now

Nelson Quinn

Before the 2022 Federal election, people were intrigued about the ‘climate action now’ signs popping up all over the place. No doubt different people interpreted the ‘climate action now’ concept in many different ways.

My aim with this address is to canvass some history illuminating how Australia has gone from acceptance of the need for action, decades of fruitless debate and now pallid action on the issues over the last 35 years or so. I have been directly involved in climate change issues since the 1987 CSIRO-sponsored conference on the implications of the changing atmosphere (Pearman, 1988). Now I am directly involved again, with the Royal Society’s work on whether Queensland’s planning arrangements are fit for purpose for coping with climate change, and as a member of the Steering Committee for ETHOS, the Griffith University program aimed at helping protect against health problems from heatwaves.

My other aim is to contribute to where to go from here so that we continue to increase our understanding of the science, learn to live with the changes already under way and increase our resilience to future changes. I emphasise rural issues, as rural decline has been much discussed in recent years and there is an obvious link with climate change issues.

What Is Climate Action?

I am assuming that climate action is usually shorthand for one or more of the following: limiting the continuing changes in the atmosphere and oceans seen since the advent of the industrial revolution; mitigating their impacts; and adapting to their consequences. These changes have been driven by human activities, primarily fossil fuel use but also others such as agriculture and the use of artificial chemicals. The changes contribute to global warming, climate change, extreme natural events,

marine ecosystem change, sea level rise potential, new or enhanced pollution effects, and changes in the stratospheric ozone layer with land-based consequences. The Australian Academy of Science has provided a good guide to climate change science (Australian Academy of Science, 2015).

Three big issues still involve uncertainty and many opinions:

- the science describing the phenomenon;
- whether and how we should seek to contain the changes; and
- how to adapt to the changes going on around us, which will continue well into the future.

Global changes are commonly conflated into ‘climate change’, thus obscuring the range and reach of other continuing global changes. Whatever is done must also contribute to dealing with, or at least not exacerbating, these other continuing global changes that have human influences as well as some natural causes. These other global change issues are:

- *Changing patterns of biodiversity and balance of life forms:* The continuing increase in the proportion of humans and their domesticated plants and animals compared with other life forms, and in their demands on the earth system leading to resource depletion, accelerated species extinction, loss of biodiversity and habitat, spread of pest plants and animals and pathogens, and a contribution to changing compositions of the atmosphere and the oceans. Some of these changes are irreversible.
- *Changes to landforms and hydrology:* There are changes to land use, land cover and hydrology (including in tidal areas and on the seabed) arising from human settlements, agriculture, mining and transport. These changes include sinking coastal cities.

- *Pollution*: Widespread pollution is causing toxification of ecosystems. Many daily human activities generate waste and pollution, in particular industrial and transport practices, and the use of fossil fuels, toxic substances and fertilisers. The effects are exacerbated where the processes are inefficient, where the ecosystems are fragile, or where air, water, people and their vehicles and animals carry the problem, often for long distances.

The changes from pollution and from biodiversity losses and changes will have a greater impact sooner than from global warming in many situations in Australia (Sheppard & Glanznig, 2012).

Some Personal Reflections on the History

There is still an audience in Australia for those who deny the science, even though probably no other topic and all its associated issues have been as keenly researched so meticulously by so many people. There are those who say the Intergovernmental Panel on Climate Change (IPCC) is political (using the term pejoratively), thereby providing a flimsy prop for dismissing its publications. I was a member of the first IPCC and responsible, with others, for marshalling the Australian contribution on the science, and, with Netherlands and New Zealand collaborators, for developing a major input on impacts and responses for coastal zones and small island States. I was the lead Australian delegate to the first plenary of IPCC Working Group III on Response Strategies, in Geneva in 1990, effectively representing the island countries in the Pacific Ocean as well as Australia. The claim by denialists that we were pursuing a political agenda rather than assembling information and seeking solutions to wicked problems would be amusing for anyone who saw us at work. John Zillman, the former Director of the Australian Bureau of Meteorology, concluded in his account of Australia's IPCC involvement that our influence was strongest in ensuring that conclusions were "based firmly on the peer-reviewed science ... and, as far as possible, kept free from non-scientific bias based on the political or policy interests of IPCC member governments or other stakeholders" (Zillman, 2008, p. 40).

The IPCC provided authoritative assessments of the state of knowledge about climate change issues. Naturally, countries continued to base their responses on their perceptions of their national interests.

Progress was not easy. The Chair of the 1990 IPCC plenary in Geneva gave me the interesting task of mediating between the Japanese and Saudi Arabian delegations with their irreconcilable differences – Japan (a net energy importer) wanted strong action while Saudi Arabia (a net energy exporter) wanted none of it. I was helped by an experienced colleague from the United States. Unsurprisingly, we went home at dawn with the irreconcilable differences in place. This was early notice that the net energy-exporting countries would probably try to frustrate international action on fossil fuels or have difficulty with wholehearted implementation.

In the early 1990s, Australia, Canada, Norway and Russia were among the few net energy-exporting countries apart from OPEC members. Now only Russia and Saudi Arabia export more fossil fuel energy than Australia does (reactions to the invasion of Ukraine may be reducing Russian exports) (Centre for Research on Energy and Clean Air, 2023; Enerdata, 2023). We must assume that our energy-exporting status will always be considered in government decision making.

The Commonwealth Cabinet debate in April 1989 about how to respond to global warming was lively. The Cabinet discussions were the longest recorded at that time (along with the Cabinet discussions in the same era about Tasmanian forestry – I was a co-author of both submissions, so perhaps it was my fault!).

The Australian Position Over Time – Slipping and Sliding

Australians were regarded as the most informed people in the world about the climate change issues in the early 1990s (Taylor, 2014). Maria Taylor in *Global Warming and Climate Change: What Australia Knew and Buried* has written an excellent description of how, from about 1995 onwards, the Australian narrative changed to one of uncertainty and doubt driven by mining and related vested interests and the Howard government. Australia, under the Abbott and Morrison governments, and

Saudi Arabia and a few other countries were aping King Canute's courtiers – he had to take them to the beach to demonstrate that he could not ignore or control natural phenomena.

In the early days, Australia was one of the leading lights scientifically and in international deliberations about what to do (Zillman, 2008). Only the United States had greater input into the establishment and early operations of the IPCC. Australia was one of the 15 countries invited to President Bush's *The White House Conference on Science and Economics Research Related to Climate Change* in 1990 (Bush, 1990a). I was involved in the establishment of the Asia-Pacific Network for Global Change Research, one outcome of *The Whitehouse Conference* (Bush, 1990b), and was a Special Adviser to the Network for a few years. The Network has prospered, but with declining Australian inputs.

The Abbott and Morrison governments reduced us to international pariahs – Australia was not invited to contribute to the 2020 Climate Ambition Summit sponsored by Britain, France and the United Nations. Seventy world leaders did contribute. These past governments dragged us from first in the world to not even in the room. They consciously trashed our higher education system, reduced CSIRO to more a consultancy than research body, degraded, misused and demoralised the Commonwealth public service, and refused to develop and fund key environmental, economic transition and adaptation programs, all the while maintaining huge subsidies to the fossil fuel industries (Campbell et al., 2021) and stalling action on developing effective future strategies for a less energy-intensive economy supported by cleaner, greener energy sources. Those governments put us at risk of paying taxes on carbon exports to other countries, a process already under way in Europe. In 2009, Tony Abbott pointed out in a Sky News interview that a simple tax would be a way to put a price on carbon. Ironically, our carbon products may end up with a simple tax imposed on them, but for the benefit of foreign rather than Australian taxpayers. There is still no end to attempts by the conservative political parties to stall effective action. For example, Bridget McKenzie, Leader of the National Party in the Senate, has been reported (on ABC News on 19 August 2022) as describing the adoption of fuel standards like those in Europe,

the United States and Japan as a tax on families, even though they would reduce transport emissions, save motorists money, increase the availability of electric vehicles and reduce Australia's reliance on imported oil (Quicke, 2022).

Unfortunately, denialism and confusion continue to be spread by people who should know better. The current Minister for Resources, Madeleine King, was quoted in *The Australian* as saying "Absolutely, 100 percent, I support the coal industry ..." (Brown, 2022), and she has also said that the government is committed to taking meaningful action on climate change (Opray, 2021). At some point she will have to get off the barbed wire fence – it doesn't work and it is not very comfortable – and commit one way or the other. She and the government have stayed firmly astride that barbed wire fence with the announcement of the release of large offshore areas for oil and gas exploration (King, 2022).

There are, however, glimmers of hope for progress. The Climate Council, an independent, evidence-based organisation on climate science, impacts and solutions, has said that the Greens' policies match the scale and pace of action the climate science demands (Climate Council, 2022) and that the Australian Labor Party's policies are acceptable but do not go far enough (Climate Council, 2021). Analysts usually conclude that not acting on global change issues can lead to higher costs and greater community disruption than acting swiftly on mitigation and adaptation (World Health Organization, 2023). We already knew this in Australia from examples like weed problems (Rossitor-Rachor, 2023), which climate change is likely to exacerbate (Invasive Species Council, 2009).

Australia is still among the highest per-capita emitters in the world, exceeded only by Oman, Bahrain, Kuwait, United Arab Emirates, Mongolia, and Trinidad and Tobago in 2021 (Our World Data, 2021). Our electricity is still 77% from fossil fuels (2020) (Department of Industry, Science, Energy and Resources, 2021), with little change over the last 60 years (Green Energy Markets, 2011), although evidently declining now (Department of Industry, Science, Energy and Resources, 2022). This decline should continue as coal-fired power stations are being abandoned by their owners; however, any move to revive coal power stations

or gas-fired power stations will increase our fossil fuel emissions again.

Our emissions from stationary energy, transport, fugitive emissions and industrial processes have continued to increase since 2005, the baseline year for the Paris Agreement emissions reduction target. State government decisions on land clearing and forestry account for almost all of the 24% reduction in emissions since 2005. The decrease from all other sources is less than 3% (Evershed et al., 2023).

Resting on Australia's small contribution to worldwide greenhouse gas emissions is another problem. Our fossil fuel exports contribute to emissions overseas, so our contribution is not as tiny as many want us to believe. Continuing to contribute to global warming anywhere will affect the whole world, including Australia.

Emissions from agriculture in Australia have declined since 2005. Although the dominant cause of climate change is the burning of fossil fuels, there have been claims that relatively meat-free diets are important because of the methane produced by herbivores such as cattle. Livestock do not add net CO₂ directly to the atmosphere; they are just part of the continuing carbon cycle involving the sun, water, plants and animals. Cattle were domesticated about 10,500 years ago (Vigne, 2011), so they cannot be blamed for a problem arising less than 200 years ago. In any event, there are already carbon-neutral livestock farming operations in Australia and overseas (Doran-Browne et al., 2016; Thorbecke & Dettling, 2019; Jones, 2010).

Agriculture is not to be confused with overall food production and consumption. Historically in Australia, 89% of energy used in the food system has been post farmgate (Gifford & Millington, 1975), so the best place to start reducing the impact of food production on climate change will be increased efficiency post farmgate.

It seems that we have not been learning from dramatic pre-industrial climatic shifts. The last time carbon dioxide levels in the atmosphere were the same as now was about three to five million years ago (the Pliocene Epoch), when temperatures became about four degrees hotter and sea levels 10 to 20 metres higher than now (Amos, 2019; Little, 2019). From Haywood (in Little, 2019, p. 2):

After studying the Pliocene for 21 years, and all

things being equal in the decades ahead, I will experience first hand a climate state that has not existed for more than 3 million years. (Haywood in Little, 2019, p. 2)

Climate Change Impacts for Australia

There are increasingly significant impacts of climate change in Australia (Cresswell et al., 2021). Some argue that we cannot link any particular event to climate change. A warmer atmosphere, however, has more energy; it will be expressed, and there is more water in a warmer atmosphere, which means increased total rainfall. Global warming has increased the risk of more extreme weather events and made many extreme events more intense, longer lasting or larger in scale than they would have been without it (Herring, 2020). The relevance of the oceans to weather in Australia is important (Wijeratne et al., 2018), thus emphasising the significance of the global warming that affects the oceans. Changes in ocean temperatures and currents will affect climates and weather everywhere.

We know, from precisely measured and recorded tests, that there are already climate changes affecting rural Australia. For example, at a practical level, wine grape harvesting in Australia and other countries has been earlier each year for at least 20 years (Ochs, 2015). I watched this happening when I lived among the vineyards in the Canberra district. More generally, there is an expectation of continuing negative impacts for food production and supply chains (Hughes et al., 2015; Malik, 2022).

The Australian rangelands are an important example, as they may be particularly vulnerable. They are already subject to strong natural variations in climate and to other natural forces such as floods, fires, dust storms, and the depredation and spread of pest plants, animals, diseases and pathogens.

Pastoral industries and the communities they support predominate in our rangelands. They are totally dependent on the environment. Short- or long-term environmental changes can have dramatic impacts for them. They would benefit from environmentally aware political leadership.

However, despite the significance of the environmental issues for the rangelands and the need for strong political commitment, leadership and action, in the 2022 Federal election in rangelands

electorates, 49% of Lingiari voters (Northern Territory), 56% of O'Connor voters (Western Australia), 57% of Durack voters (Western Australia), 59% of Grey voters (South Australia), 68% of Parkes voters (New South Wales) and 75% of Maranoa voters (Queensland) gave their first preferences to candidates who arguably have failed them or are science deniers who have sold out to fossil fuel interests, and who have preferred, supported or not objected to decisions that were unfair, divisive and that increased inequality.

Strong national political leadership is essential. My direct experience has been with the Commonwealth Government, beginning with Menzies. Since then, Whitlam and Hawke have been the only Prime Ministers committed to environmental improvement (it is too soon to judge Albanese's level of commitment).

The Task Before Us – Slowing Climate Change

There is a big job ahead of us to convince everybody that the science is sound, noting that continuing research is needed for both weather (what happens now) and climate (weather patterns over time), for the impacts of the changes, and for adaptation systems and practices.

The highest priorities for climate change avoidance are the same as they were in the early 1990s, i.e.:

- ceasing the extraction and usage of fossil fuels – they should be immediately, but realistically, phased out on an accelerating trajectory;
- electrifying everything (see Saul Griffith's *The Big Switch: Australia's electric future*);
- stopping, or at least severely limiting, land clearing, whether for urban, infrastructure or farming purposes;
- increasing afforestation, including in towns and cities, and on public lands such as transport corridors; and
- increasing soil carbon.

We can all continue to urge governments, businesses and individuals to continue seeking increased energy efficiency and less energy-intensive business and personal activities.

No one says the necessary transformations can

be achieved overnight, but we would be well down the track if we had started when our governments first recognised the need more than 40 years ago.

The Task Before Us – Adaptation

Adaptation was under notice back in the 1990s, although the emphasis then was on the immediate need to understand and deal with greenhouse gas emissions. John Zillman, as head of the Bureau of Meteorology, introduced the idea of a National Climate Program, but it did not get the attention it deserved as we dealt with the more immediate climate change issues (Zillman, 2008, p. 27) – a bit like drought responses, where solutions that simply restore the pre-drought situation are still pursued. As a result, the cycle is repeated endlessly rather than governments implementing long-lasting coping, adaptation and resilience strategies. Many people have advocated action on a climate strategy and broader approaches to drought problems, but we must continue to try to get these ideas on political agendas.

The need for attention to adaptation of agriculture to climate change was canvassed substantially at a CSIRO-organised conference in 1987, including by people like Mark Howden and Graeme Hammer who have been contributing to agriculture and climate change issues ever since. Indeed, many of the contributors to the 1987 conference have continued working actively on climate change issues.

Rural communities have often had to cope with changes driven by outside forces. Adaptation on a voluntary or involuntary basis has been common in many places in rural Australia with the constantly changing situations over the years. Where I grew up in southern Queensland, hundreds of people have had to find new ways to make a living and find new lifestyles because of changes over the last 50 years or so.

To illustrate: there were dairy farms everywhere, as well as maize and peanut cropping, pigs, fruit and vegetable production, and timber. Now there are only one or two dairy farms, few crops, no sawmills or timber industry, a closed meatworks and a closed *Duboisia* cultivation industry. The cheese factory is gone. The dairy farms went the way of the thousands of others in Queensland. The sawmills and the timber industry disappeared because of exhaustion of supply. The meatworks, once one of the ten biggest

export businesses in Queensland, closed because of decisions by New South Wales beef industry interests. The cheese factory closed because of decisions by Melbourne business interests. The local *Duboisia* cultivation industry wound down because of decisions in Germany and India. Now beef production, wine and tourism are major local industries. These are big changes that have been successfully absorbed by the local communities. There will no doubt continue to be changes driven by outside forces, including climate change which may have severe impacts on the wine industry.

Now from the local to the general: the number of dairy farms in Queensland has declined from 3052 in 1980 to 327 in 2020 (Long, 2022), with more closing since then. This decline has been caused by deregulation in 2000, worsening terms of trade, closing of dairy co-operatives (based on appallingly bad advice from experts), and the concentrated control of food and grocery sales in Australia. This dramatic change over only 40 years has had enormous social, economic and financial negative impacts, as well as reducing the resources available for sustainable land management.

One likely climate change outcome will be the continued, more or less unchecked spread of lantana, one of Queensland's worst weeds, and of other weeds. Germaine Greer describes in her book *White Beech* how hard it is to rehabilitate old dairy farm country taken over by weeds. Don Watson describes similar environmental, social and economic transformations over many years in many parts of Australia in *The Bush*.

There is no shortage of well-developed ideas about what needs to be done.

Sher and Sher's report to the Commonwealth Government in 1994, *Beyond the Conventional Wisdom: Rural Development as If Australia's Rural People and Communities Really Mattered* (Sher & Sher, 1994), advocated a community-centred (priority for the wellbeing of communities) rather than industry-driven basis (supporting particular rural industries) for rural development. The 2002 Australian Greenhouse Office issues paper, *Developing a Strategic Framework for Greenhouse and Agriculture*, covered adaptation needs, including incidentally the need for more agroforestry. The key messages in a 2010 CSIRO study, *Adapting Agriculture to Climate Change*, were about

generating better understanding of issues, recognising differences across the country, and seeking flexible and 'win-win' solutions. The CSIRO study emphasised the need for an effective system for monitoring climate change impacts and human adaptive responses, so that policy and management can develop ahead of the game.

Additionally, there are *Australian rangeland futures: time now for systemic responses to inter-connected challenges* by Barney Foran and his colleagues in 2019 (Foran et al., 2019), with Barney's update in 2021 (Foran, 2021), and the rangelands work by The Royal Society of Queensland (Sattler, 2020).

The Commonwealth Government released a *National Climate and Resilience and Adaptation Strategy* in 2021 (a successor to the first *Strategy* in 2015). This is weak on practical action and full of fanciful claims of action that are entirely inconsistent with the history.

There are examples of local communities initiating action about their future, with help from advisers like the Rural Economies Centre of Excellence in Toowoomba, which has helped with establishment of the Red Earth Community Foundation in the Burnett area. The Bega Valley Circular Economy Initiative is another example. These two are linked because of the involvement of Bega Cheese in both.

What We Lack

There is no immutable law dictating rural decline or exploitation. So, what is holding us back? There are at least three things that must inevitably be faced as the world changes around us. One is a national decision or choice about how to marshal and deploy resources to generate economically secure and socially vibrant rural communities while protecting and restoring the natural environment.

The second is a new sense of how to relate to our natural systems. Not surprisingly, I commend the outcome of the Australian Royal Societies' work on a new stewardship approach based on Indigenous approaches developed over thousands of years. The Australian Royal Societies advocate adoption of a custodial and obligation ethic involving a sense of Country that encompasses all the knowledge, cultural norms, values, stories and resources within a particular area to contribute to overall health and

wellbeing for people and their environment, and to guarantee wellbeing for future generations (Quinn, 2021).

Collaborative and cooperative relationships to support custodianship are necessary for success. The effort led by CSIRO's Rocio Ponce Reyes in the northern brigalow belt is an excellent example – *Priority Threat Management for Imperilled Species of the Queensland Brigalow Belt* (Ponce Reyes et al., 2012). Different interests worked together to develop common visions, understand each other's perspectives, and agree on cost-effective action that all could accept.

The third is government arrangements that support regional and rural development as a whole. Jonathan Sher rightly pointed out in his keynote address to the International Conference held by the Rural Education Research and Development Centre in Townsville in 1994 that at the Commonwealth level, rural and regional issues had no central focus but tended to be driven by farming concerns (McSwan & McShane, 1994). He did note that John Kerin as Minister for Agriculture had a wider vision, which I know to be true from personal involvement with John, but that this disappeared when he left. This problem is illustrated by the current Drought Hub system, which is all about farmer viability rather than the much wider range of interests described by Sher. Profitable beef farms with no easy access to health, education and other services are not an attractive prospect.

The current Commonwealth Government has continued the problem, as history suggests that the agriculture ministry will retain its narrow focus, the environment department will remain underfunded and struggling to make an impact, and the regional development function in the infrastructure ministry will be overwhelmed by its major infrastructure, transport and communications functions.

Unless the following three issues are addressed effectively, it would be difficult to adopt new approaches for the Australian rangelands, such as those suggested in 2009 by Mark Stafford Smith and Julian Cribb in *Dry Times: Blueprint for a Red Land*. They suggested:

- recognising that domestic livestock are part of the landscape;
- helping graziers develop into natural resource

managers who strive to meet multiple objectives; for example, control of alien and feral pests, restoration and conservation of biodiversity and ecological integrity, fire management; and

- seeking multiple sources of income with an 'at harmony with nature' approach with social and economic benefits.

There has been no national decision to overcome the environmental, social and economic decline in our rangelands, or to prepare for a changing natural environment driven by global changes. Neither has there been a satisfactory resolution of the conflict between a production approach to land management and the need for a custodial and obligation approach to serve both current and future needs. The government administrative arrangements retain the narrow focuses, fragmentation and conflicting policies and laws that have hampered, even prevented, progress.

Funding the transformation Australia needs remains a problem. It should be seen as an investment, not a cost. Australia could catch up with Japan in efficient use of resources (International Energy Agency, 2021) for the benefit of all of us with a less energy-intensive economy, which is one outcome of effective climate action. This investment would deliver savings in the health system, with fewer lives lost from extreme events. There would be less damage from extreme events and reduced reconstruction costs.

The need is to make a start. Barney Foran suggested, in the combined Royal Societies' work on a new stewardship approach, that we need to develop interventions to deal with sparse population, remoteness and social uncertainty, beginning with development of regional plans with five to ten issues aimed at attracting public money and overcoming skills decline. The Burnett example with the Red Earth Community Foundation mentioned above is a start, but we need more so that there is at least a representative cover of Queensland, including the rangelands and the tropics. These attempts will require governments to work with local interests and to invest in them. For example, the Commonwealth Government should be lobbied to adopt the proposals in the 2020–2021 budget submission from the Australian Conservation Foundation seeking:

- \$4.5 billion annually for rural and regional community renewal, and help for communities impacted by extreme natural events to rebuild;
- an increase of almost \$1.5 billion annually to transform Australia's economy into a clean energy superpower; and
- \$2 billion annually to protect and restore wildlife habitat affected by bushfires, droughts, and decades of destroying natural habitat.

Conclusions

Australia has failed to act quickly enough to slow and accommodate climate change and other global changes, rural decline has continued, and too many of our influential people are not committed to effective action. We must accelerate protection and restoration of our natural assets, adopt some of the proposals for reversing rural decline, and lobby our political and business leaders to get on with it, as well as reduce the exploitation and use of fossil fuels.

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